TECHNICAL
REPORT

Estimating the Benefits of the GridWise Initiative

Phase I Report

WALTER S. BAER, BRENT FULTON,
SERGEJ MAHNOVSKI

RAND SCIENCE AND TECHNOLOGY

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Preface

This report documents the results of the first phase of a two-phase study conducted for the Office of Electricity Transmission and Distribution of the U.S. Department of Energy (DOE) and the Pacific Northwest National Laboratory (PNNL) to estimate the benefits that would result from implementing the GridWise™ initiative, which is intended to accelerate the use of advanced communication and information technologies in the U.S. electricity system. DOE and PNNL seek a better understanding of the character and magnitude of benefits—for electricity suppliers, end-users, and society at large—to inform both public and private sector decisions about GridWise-related research and development (R&D) and implementation strategies.

This study first develops an analytic framework for characterizing and estimating such benefits, then makes preliminary quantitative estimates for the most important benefit categories. The quantitative estimates represent gross benefits that do not include R&D and implementation costs, which will be estimated in Phase II of the study. Assumptions and other input variables for the benefit calculations are clearly delineated, both to indicate the sensitivity of benefit estimates to such inputs and to provide a basis for improving the estimates in Phase II.

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Summary

This report presents the initial (Phase I) results of a two-phase project undertaken to characterize and estimate the benefits of applying advanced communications and information technologies, through the GridWise™ initiative, to bring the aging U.S. electricity grid into the information age.

GridWise is a vision, a concept, and a national initiative developed by the U.S. Department of Energy (DOE), the Pacific Northwest National Laboratory (PNNL), and participants from the electricity industry. GridWise seeks to link electricity suppliers and end-users with high-speed networks that provide real-time information about system capacities, demand, prices, and status. Its proponents anticipate that the integration of communications and information with the electricity grid will facilitate competitive, efficient markets for power, enable each participant to actively manage its own production and consumption decisions, help the system balance supply and demand under both normal and stressful conditions, and in general provide diagnostic information and tools to better manage both system operations and end-user applications.

The essence of GridWise is the revealing of value to all parties through information and communications, so that the least-cost resources are used to meet new demand for power and its underlying infrastructure. Markets may be the simplest and most transparent way to reveal value, but regulatory approaches using incentives and resource bidding appear workable as well. Whether in a regulated utility environment or in a deregulated market-based system, advanced information and communications technologies are the keys to revealing value and enabling stakeholders to act on the opportunities presented to them. While this analysis relies on a competitive market model to characterize and estimate benefits from implementing GridWise, we recognize that such benefits may also be realized in a regulated system or in one with both competitive and regulated components.

Smoothing out the daily peaks and valleys of electricity production and consumption can benefit both electricity suppliers and end-users. With GridWise, end-users will see time-varying prices that reflect high supply costs when power consumption peaks and lower costs at other times. Users can then adjust their peak and off-peak demands, either manually or by programming their appliances and other electrical equipment to respond to price signals. This

"demand response" will result in less power consumption during high-cost peak periods and the shift of some peak usage to lower-cost off-peak times. Changes in power usage due to demand response will generally be greater for commercial and industrial facilities than for residential end-users. Overall, end-users will gain from lower expenditures for power, while suppliers will benefit from reduced operating costs and better utilization of their generation, transmission, and distribution assets.

Enabling end-users to interact directly with the grid can also help the electricity system respond to equipment failures, weather-related emergencies, and other stressful conditions. At present, each of the ten North American Reliability Council (NERC) regions must maintain enough excess generating capacity to supply system demand if a large generating unit or transmission line fails. In the GridWise concept, much of that reserve could be provided by smaller generating units located at or near end-user sites or by end-user loads themselves. The GridWise vision of collaborative networks, ubiquitous information flows, distributed intelligence, and automated control systems promises important additional benefits in terms of improved power quality, reliability, and security, as well as energy efficiency.

The Phase I analysis develops a microeconomic framework for making quantitative estimates of demand response and other benefits from the widespread implementation and adoption of GridWise. To establish a baseline without GridWise, we use the projections through 2025 of electricity system capacities, power consumption, and prices contained in the most recent *Annual Energy Outlook* (AEO) published by the U.S. Energy Information Administration. We then phase in GridWise over 20 years and compare the results with those from the AEO baseline.

To explore the sensitivity of benefits to the input data and assumptions, we develop a series of scenarios representing different, but plausible, development paths for GridWise. Benefits for each scenario are calculated as the present value over 20 years of the cash flow differences from the AEO baseline projections.

Figure S.1 compares the benefits calculated for five scenarios:

- A **"nominal" scenario** with midrange values chosen for important input variables such as GridWise market penetration among end-users and within the transmission and distribution (T&D) grid; demand response parameters; electricity market competitiveness; and GridWise impact on generating reserve margins, power quality and reliability (PQR), and energy efficiency in buildings.

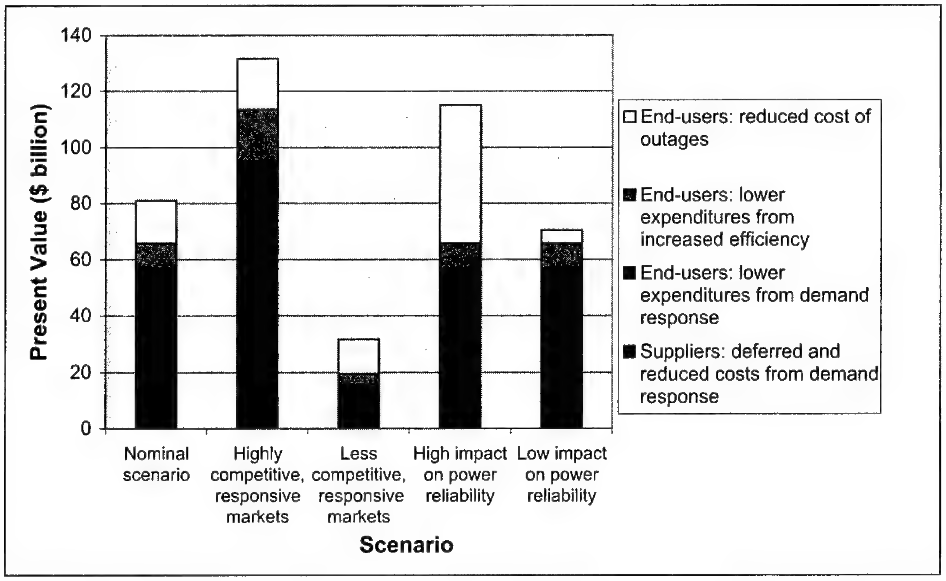

Figure S.1. Supplier and End-User Benefits from GridWise, by Scenario

- A **highly competitive and responsive markets scenario** with higher values for GridWise market penetration among end-users, demand response, impact on generating reserve margins, and electricity market competitiveness.
- A **less competitive and responsive markets scenario** with correspondingly lower values for GridWise market penetration among end-users, demand response, impact on generating reserve margins, and electricity market competitiveness.
- **A high-PQR-impact scenario** with higher pre-GridWise costs of power outages and disturbances for end-users and greater GridWise efficacy in reducing these costs.
- A **low-PQR-impact scenario** with less GridWise efficacy in reducing outages and disturbances.

The systemwide benefits from demand response accrue partly to industry suppliers (the bottom segment of each bar) and partly to end-users (the next segment of each bar). The split depends largely on the extent of market competitiveness and responsiveness. In the nominal scenario, end-users receive 40 percent of the demand response benefits, passed on primarily as lower off-peak prices, which result in lower total expenditures for power. Suppliers receive the rest, benefiting from deferred and reduced costs that substantially outweigh the impact of lower end-user spending. Including benefits from improved PQR

and energy efficiency brings the present value total of benefits to suppliers and end-users to $81 billion.

When electricity markets are both highly competitive and responsive, end-users receive an even larger share (60 percent); but the total benefits from demand response are greater, so the industry suppliers also receive large benefits. Total benefits, including improved PQR and energy efficiency, rise to $132 billion. In the less competitive and responsive market scenario, suppliers get most of the demand response benefits (75 percent), but there is considerably less to divide. Total benefits, including improved PQR and energy efficiency, are only $32 billion, $100 billion less than those for the highly competitive and responsive scenario. The last two scenarios in Figure S.1, in which GridWise has high and low impact on power quality and reliability, yield total benefits of $115 billion and $70 billion, respectively.

These results clearly show that the estimated gross benefits from GridWise can be quite large, exceeding $100 billion in two of the five scenarios. However, the variance among estimates is also very large, depending, of course, on the input data and assumptions. At this early stage of GridWise development, many of the input variables and projections are highly uncertain. Consequently, we believe that delineating the range of benefits based on plausible input variables is more useful than trying to converge on a single "best estimate."

Our Phase I analysis does not include quantitative estimates of other categories of possible GridWise benefits, notably,

- Lower costs of capital for generation, transmission, and distribution investments.
- Integration of smaller-scale, distributed generation and related assets with the grid.
- Reduced emissions and other environmental externalities.
- Intangible benefits.
- End-user productivity gains.

Based on our preliminary analysis, benefits in the first three categories appear to have relatively small present values compared with those shown in Figure S.1. The latter two categories could conceivably yield much larger benefits, but they depend on assumptions that at this point seem very difficult to validate. In Phase II of this project, we will evaluate these benefit categories more fully and will develop estimates of the costs to implement GridWise.

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We acknowledge with thanks the insightful comments and suggestions we received on earlier drafts from Clark Gellings (EPRI), Ingo Vogelsang (Boston University and RAND), Robert Pratt (PNNL), John DeSteese (PNNL), Mark Bernstein (RAND), and Sunil Cherion (Spirae, Inc.). We also benefited from colleagues at RAND, PNNL, EPRI, DOE, and several other institutions who contributed their data, knowledge, and advice to further this study. Finally, we thank Lisa Sheldone and Janet DeLand, who helped us edit and prepare this document for publication.

Acronyms and Abbreviations

AEO	Annual Energy Outlook
CHP	combined heat and power
DER	distributed energy resources
DG	distributed generation
DOE	U.S. Department of Energy
DSM	demand-side management
EIA	U. S. Energy Information Administration
EMS	energy management system
GDP	gross domestic product
HVAC	heating, ventilation, and air conditioning
kW, MW, GW	kilowatt, megawatt, gigawatt
kWh	kilowatt-hours
NERC	North American Reliability Council
O&M	operation and maintenance
OETD	Office of Electric Transmission and Distribution
PNNL	Pacific Northwest National Laboratory
PQR	power quality and reliability
R&D	research and development
RTP	real-time pricing
T&D	transmission and distribution
UPS	uninterruptible power supply

1. Introduction

The GridWise Vision

The electricity system serving the United States, once a model of modernity for the entire world, is in great need of modernization today. A recent paper prepared by the Office of Electric Transmission and Distribution (OETD) of the U.S. Department of Energy (DOE) states the problem succinctly:

> America's electric system, "the supreme engineering achievement of the 20th century," is aging, inefficient, and congested, and incapable of meeting the future energy needs of the Information Economy without operational changes and substantial capital investment over the next several decades.[1]

Moreover, the OETD paper continues, "The revolution in information technologies that has transformed other network industries in America (e.g., telecommunications) has yet to transform the electric power business."[2]

GridWise™ is a vision, a concept, and a national initiative developed by DOE, the Pacific Northwest National Laboratory (PNNL), and industry leaders, with the goal of

> moving our industrial-age electrical grid into the information age.... GridWise seeks to modernize the nation's electric system—from central generation to customer appliances and equipment—and create a collaborative network filled with information and abundant market-based opportunities.... Using advanced telecommunications, information and control methods, we can create a "society" of devices that functions as an integrated, transactive system.[3]

Moving GridWise from vision to reality, however, will require large, sustained efforts over many years and investments of many billions of dollars. Will the benefits—to electricity suppliers, electricity end-users, and society at large—justify the costs of developing and implementing GridWise? What are those benefits, and how well can they be estimated today? These are the principal questions this study explores.

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[1] OETD, 2003, p. iii.

[2] Ibid, p. iv.

[3] GridWise Alliance, 2003.

How GridWise Will Produce Benefits: An Overview

GridWise and related concepts of a future electricity system such as Grid 2030 (OETD, 2003), Electricity Sector Framework for the Future (EPRI, 2003b),[4] The Smart Energy Network (Mazza, 2003), and The Energy Web (Silberman, 2001) envision all suppliers and end-users linked by high-speed telecommunications and information networks that provide real-time information about system capacities, demand, prices, and status. Integration of communications and information with the electricity system will facilitate competitive, efficient markets for power; enable each participant to actively manage its own production and consumption decisions; help the system balance supply and demand under both normal and stressful conditions; and in general provide diagnostic information and tools to better manage both system operations and end-user applications.

The essence of GridWise is the revealing of value to all parties through information and communications, so that the least-cost resources are used to meet new demand for power and its underlying infrastructure.[5] Markets may be the simplest and most transparent way to reveal value, but regulatory approaches using incentives and resource bidding appear workable as well. Whether in a regulated utility environment or in a deregulated market-based system, advanced information and communications technologies are the keys to revealing value and enabling stakeholders to act on the opportunities presented to them. While this analysis relies on a competitive market model to characterize and estimate benefits from implementing GridWise, we recognize that such benefits may also be realized in a regulated system or in one with both competitive and regulated components.

Increasing System Efficiency Through Demand Response

In a market environment, a critical component of GridWise-enabled information flows will be dynamic end-user prices for electricity that are frequently updated in line with the actual costs of generating and delivering power.[6] Dynamic prices will reflect high supply costs when power consumption peaks and lower

[4] EPRI, 2003a, and Gellings, 2003, present similar concepts for the future power delivery system.

[5] Robert Pratt, PNNL, private communication, 2004.

[6] Dynamic prices can take many forms, ranging from time-of-use prices, which are preset by time of day or day of week, to real-time prices (RTP) that vary on an hourly basis or even more frequently when electricity supply costs are volatile. This analysis posits that GridWise will enable real-time dynamic prices. For further discussion of pricing alternatives, see Rosenfeld, Jaske, and Borenstein, 2002; and Faruqui et al., 2002.

costs at other times. End-users receiving dynamic prices will be able to adjust their peak and off-peak demands, either manually or by programming their appliances and other electrical equipment to respond automatically to price signals. This "demand response" will result in lower power consumption during high-cost peak periods and the shift of some peak usage to lower-cost off-peak times.

As one illustration, commercial and industrial cooling systems can use dynamic price information to reduce energy costs while keeping temperatures within a desirable range. On a hot day, the system can be programmed to run at full capacity before and after the peak, so that it can use less power for cooling when prices are highest. As a residential example, a household participating in a dynamic pricing program could have a "smart meter" with programmable controls to run the family dishwasher when electricity prices are low and avoid washing when prices are high, thus lowering overall household expenditures for power.[7] In general, changes in power usage due to demand response will be greater for commercial and industrial facilities than for residential end-users.

Demand response not only benefits end-users but also increases the capacity utilization and operating efficiency of the power system. Traditionally, generation, transmission, and distribution capacities must be sized to handle peak electrical loads and are underutilized at other times. As a result, the national average load factor of all electricity system assets is only about 55 percent.[8] By reducing peak loads and "flattening" the daily demand pattern for electricity (Figure 1.1), demand response makes it possible to supply electricity reliably throughout the day and year with fewer generating plants and less transmission and distribution (T&D) infrastructure, all operating at higher capacity factors. Better asset utilization will improve the economic performance of the electricity system as a whole and will bring financial benefits to most electricity suppliers.

Using Load and Distributed Resources to Keep the Grid Stable

Enabling end-users to interact directly with the grid can also help the electricity system respond to equipment failures, weather-related emergencies, and other stressful conditions. At present, each of the ten North American Reliability Council (NERC) regions must maintain enough excess generating capacity on

[7] Such controls would be likely to include an override feature to permit running the appliance at high-cost periods—for example, during a party.

[8] OETD, 2003, p. 7.

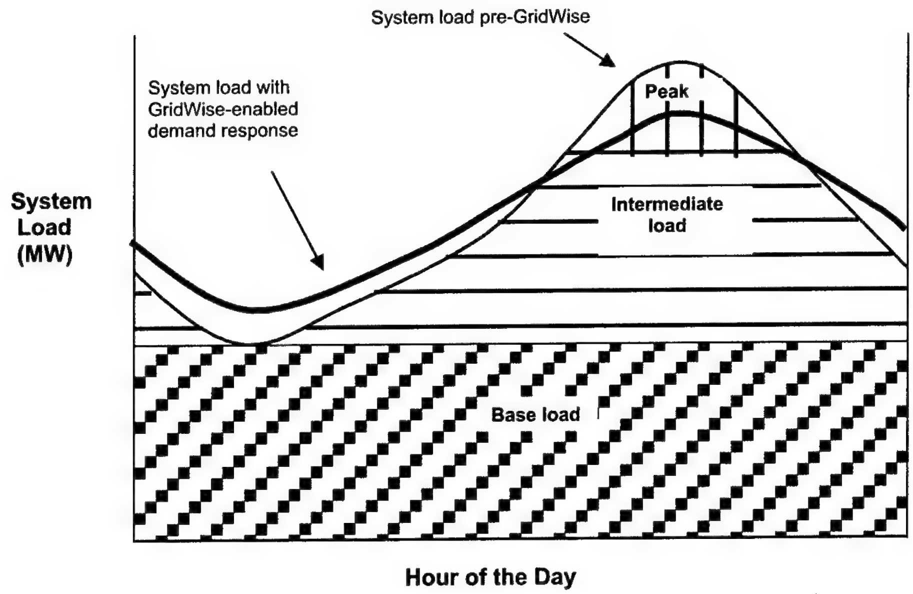

Figure 1.1. Projected GridWise Impact on a Typical Daily Load Curve

line (spinning reserve) or quickly available (supplemental reserve) to continue supplying system load if a large generating unit or transmission line fails. In the GridWise concept, much of that reserve could be provided by smaller, distributed generation (DG) units located at or near end-user sites[9] or by end-user loads themselves.

As an example of utilizing loads as reserves, PNNL has designed computer chips that can be integrated into refrigerators, air conditioners, hot-water heaters, and other household appliances to continuously monitor the grid's status.[10] If a Grid-Friendly Appliance™ senses abnormal line frequency fluctuations, which are often the first warning signs of generation or T&D inadequacy, it can be programmed to shut down for a few seconds or minutes. Brief power interruptions will not damage these appliances or degrade the services they provide to the end-user; but isolating them from the grid, even momentarily, can help relieve whatever stress the system may be experiencing. GridWise envisions large numbers of Grid-Friendly Appliances not only helping the system respond to stress or emergency situations[11] but also contributing to normal stabilization

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[9] Small-scale generators, energy storage units, and related facilities and equipment are known as *distributed energy resources* (DER).

[10] PNNL, 2003.

[11] Again, an override feature is highly likely to be included as part of a Grid-Friendly Appliance. Consequently, the actual response of the system must be estimated on a probabilistic basis (Donnelly, 2003).

functions known as *ancillary services.*[12] Beyond direct benefits to end-users from greater reliability, using load and distributed resources as system reserves would reduce the costs of building and maintaining centralized generating units for these purposes.

Improving Electricity System and End-User Operations

The GridWise vision of collaborative networks, ubiquitous information flows, distributed intelligence, and automated control systems suggests a myriad of additional benefits, large and small, on both the supplier and end-user sides of the smart meter. Networked monitoring devices coupled with smart diagnostic tools can help transmission operators and distribution utilities identify maintenance problems before they lead to equipment or infrastructure failures. When natural disasters, accidents, or malicious acts occur, they can be detected and repaired quickly, often through automated, "self-healing" grid responses.

For electricity end-users, the integration of networked information, communication, and distributed controls will increase the value of a networked energy management system (EMS) in residences, as well as in commercial and industrial buildings.[13] GridWise-enabled information flows can also enhance the value of customer investments in uninterruptible power supply (UPS) or other equipment to protect sensitive end-user devices. In general, GridWise can help end-users manage more efficiently not only their power usage but also the power quality needed for their specific applications.

Distributed control systems will enable DER to be well integrated with grid assets and infrastructure. This will not only improve overall system reliability but will also enable end-users to sell power to the grid when prices exceed the onsite generating cost and further improve the economics of using DER for producing electricity or combined heat and power (CHP).

Study Objectives and Organization of this Report

This study was commissioned in the spring of 2003 to build an analytic framework for estimating the benefits from the widespread implementation of the GridWise concept and to make a quantitative net assessment of GridWise benefits and costs. The project has been incrementally funded in two distinct

[12] Kannberg, 2003. See also Ford, 2002, and Kirby and Hirst, 2003, for more detailed discussion of ancillary services in the GridWise context.

[13] Rabaey et al., 2001.

phases. The objectives of Phase I, an initial six-month scoping effort, were to identify and characterize the major categories of GridWise benefits, develop the analytic framework, and make preliminary estimates of the most important benefits. Based on the Phase I results, Phase II will involve a more extensive analysis of benefits, as well as GridWise research and development (R&D) and implementation costs, resulting in a quantitative net benefit assessment.

This report documents the results of the Phase I analysis, most of which was completed by the end of October 2003. Chapters 2 and 3 set out the analytic framework, models, and approach to estimating benefits, leading to the preliminary quantitative estimates of benefits presented in Chapter 3. Comparisons with other benefit calculations, as well as limitations of the Phase I results, are discussed in Chapter 4. Finally, Chapter 5 discusses next steps and outlines a plan for conducting the more comprehensive, quantitative net benefit assessment in Phase II.

2. A Framework for Assessing GridWise Benefits

Initial Taxonomy of Benefits

As the first step toward building an analytic framework for assessing benefits that would result from implementing the GridWise vision, we developed a list of potential benefits, based on our review of previous studies and discussions with electricity stakeholders and analysts.[14] Table 2.1 shows the initial list, organized by three principal stakeholder groups to whom the benefits will accrue: industry suppliers of electricity, electricity end-users, and society at large.

Table 2.1

Initial Listing of Potential GridWise Benefits, by Stakeholder Group

Potential Benefits to Utilities and Other Electricity Suppliers

- Generation and storage
  - Reduced peak loads; flatter load-duration curve
  - Deferred capital costs of new generating plants
  - Lower cost of capital
  - Reduced generating reserve margins
  - Increased cash flows and profits from higher capacity factors, increased market transactions, and other factors
  - Improved monitoring and control of operations
  - Greater system stability
  - Lower, more predictable operation and maintenance (O&M) costs
  - Lower, more stable fuel costs
  - Reduced cost of emission controls or marketable permits
  - Reduced risk and uncertainty
  - Elimination or moderation of boom-bust construction cycles
- Transmission and distribution (T&D)
  - Reduced peak loads
  - Deferred capital costs of new T&D infrastructure
  - Lower cost of capital
  - Increased cash flows and profits from higher capacity factors, market transactions, decreased congestion and other factors
  - Improved monitoring and control of operations

[14] Studies that have directly estimated benefits of GridWise or similar initiatives include Kannberg et al., 2003; EPRI, 2003b; EPRI, 2001c; Iannucci et al., 2003; McKinsey & Co., 2001; and Sutherland, 2003. Other papers and reports that touch on or contribute to such estimates of benefits are listed in the References.

Table 2.1 (continued)

- Lower costs of outages
- Lower T&D line losses
- Lower, more predictable O&M costs
- Lower costs of ancillary services
- Reduced risk and uncertainty

Other industry stakeholders

- More opportunities for distributed generation (DG) and related distributed energy resources (DER)
- More opportunities for demand-side management (DSM) products and services

Potential Benefits to Electricity End-Users

- Improved ability to actively manage loads (peak and off-peak)
- Improved diagnostics, monitoring, and control of internal processes and operations
- Lower expenditures for power through lower demand charges, reduced power use at high-cost peak periods
- Reduced losses from power outages and disturbances
- Avoided cost of backup power and power conditioning systems
- Lower costs of interconnecting on-site generation with the grid
- Increased revenue from sales of on-site generated power or ancillary services
- More efficient use of energy through combined heat and power (CHP) and advanced energy management systems (EMSs)
- Better matching of power quality and reliability to end-user needs
- Productivity gains from improved or redesigned business processes
- Reduced risk and uncertainty

Potential Benefits to Society

- Greater energy security, robustness, and resilience
- Reduced emissions and other environmental costs
- Better accommodation of renewables and other intermittent power sources with the grid
- Facilitation of electricity industry restructuring
- Fewer opportunities to manipulate the system and make windfall gains
- Greater public confidence in the electricity system

Building an Analytically Tractable Framework

Moving from this long list to a set of benefits that can be clearly characterized and quantitatively estimated requires dealing with a series of analytic problems and issues. Three of the principal issues are:

- Estimates must distinguish between intermediate and final benefits.
- Benefits often are not independent of each other.
- Externalities and intangible benefits are inherently difficult to quantify.

These issues are discussed in turn below.

Estimates Must Distinguish Intermediate from Final Benefits

There are often several steps between GridWise-enabled changes and the benefits they bring to particular stakeholders in the power system. It is thus not surprising that the initial list (Table 2.1) includes intermediate benefits as well as quantifiable "final" benefits to electricity suppliers and end-users.

As one example, the demand response enabled by GridWise will permit end-users to actively manage their power consumption and bring about reductions in system peak loads. These we term *intermediate* benefits. *Final* benefits, in our framework, include the reduction in end-user expenditures for power that results from active management of peak and off-peak loads, as well as suppliers' deferred capital costs, reduced operating costs, and higher capacity factors that enable greater cash flows and profits. Table 2.2 reformulates benefits to electricity suppliers and end-users in terms of intermediate and final benefits.

Benefits Often Are Not Independent of Each Other

Many of the final benefits themselves are closely linked and must be estimated together. For example, if GridWise-enabled demand response results in electricity end-users cutting their peak demand by 1 megawatt (MW), the system as a whole benefits from the deferred cost of 1 MW of new peak generating capacity plus the associated T&D investment. These benefits are shared between suppliers and end-users. Most end-users benefit from reduced expenditures for power, and most baseload generators benefit from higher revenues and profits due to increased capacity factors as some load shifts from peak to off-peak. But not every supplier will benefit: total revenues to suppliers will decrease, and some peak generating plants will see their cash flows and profits decline.

For demand response, one can readily show that the total system cost savings equal the sum of benefits to suppliers and end-users.[15] As a consequence, separately adding estimated benefits from deferred capital and operating costs to those from higher capacity factors and those from reduced end-user expenditures would constitute double counting. Instead, as developed in the

[15] The overall benefits to electricity suppliers, $B_s = \Delta P = \Delta R - \Delta C$, where ΔP, ΔR, and ΔC stand for the differences, after GridWise is implemented, in profits, revenues, and costs, respectively. The benefits to end-users from reduced expenditures, $B_u = -\Delta R$, so that $B_s + B_u = -\Delta C$; that is, the sum of benefits to suppliers and end-users is equal to the system cost savings. This result holds for constant electricity output; if output varies, there can be additional (deadweight) benefits and costs.

Table 2.2

Intermediate and Final Benefits Enabled by GridWise

GridWise Enabler	Intermediate Benefits	Final Benefits
Demand response	Suppliers: Reduced peak loads Higher capacity factors Reduced uncertainty, risk Fewer stranded assets Reduced boom-bust cycles End-Users: Active load management Competitive power markets Reduced uncertainty, risk	Suppliers: Deferred capital costs Lower O&M, fuel costs Lower cost of capital Higher cash flows, profits End-Users: Lower power expenditures
Load as reserves	Suppliers: Lower generating reserves Competitive markets for ancillary services Improved system stability End-Users: Fewer outages, power disturbances	Suppliers: Deferred capital costs Lower O&M, fuel, ancillary services costs Higher cash flows, profits End-Users: Reduced costs of outages Reduced backup power cost Revenues or credits from ancillary services sales
Improved diagnostics, monitoring, and control	Suppliers and end-users: Predictive maintenance, self-healing networks Fewer outages and power disturbances Plug-and-play DG and DER interconnection More EMS, DSM innovations PQR better matched to end-user needs	Suppliers: Lower O&M, emission control costs End-Users: Reduced costs of outages Revenues from sales of onsite generated power Cost savings from CHP, EMS Productivity gains from redesigned processes

demand response estimates calculated in the next chapter, the benefits accruing to different stakeholders must add up to the benefits for the entire system.

Another kind of double counting can occur if benefits to society are estimated separately from, and then added to, similar benefits to electricity suppliers and end-users. For example, most of the economic benefits that result from increasing the reliability of the power system flow directly to suppliers and end-users and should be estimated for these stakeholders. What remains in the "society" category are those benefits from increased reliability that are not captured directly by other stakeholder groups, such as the national security value of a less vulnerable grid. Estimating benefits to society thus becomes principally an

assessment of public goods or externalities whose benefits and costs are not reflected in private transactions.

Externalities and Intangible Benefits Are Difficult to Quantify

While a large and growing literature focuses on characterizing and estimating public goods and externalities surrounding energy production and use,[16] measuring the national security value of making the electricity grid less vulnerable or the societal benefit of cleaner air remains notoriously difficult. Efforts to quantify intangible benefits, such as greater public confidence in the electricity system or local control of electricity generating plants, raise even more problematic issues. As a consequence, in Phase I we concentrate on estimating final benefits to electricity suppliers and end-users, such as those shown in Table 2.2, leaving estimates of externalities and intangible benefits to Phase II of this work.

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[16] Lovins et al., 2002, include many public good and intangible benefits in their list of 207 benefits from smaller-scale, distributed energy resources.

3. Phase I Estimates of GridWise Benefits

In this chapter, we make preliminary estimates of GridWise benefits.[17] To establish a baseline without GridWise, we use the projections through 2025 of system capacities, electricity consumption, and prices contained in the most recent *Annual Energy Outlook* (AEO 2003) published by the U.S. Energy Information Administration (EIA 2003). The baseline data and projections are summarized in Tables 3.1 and 3.2 below and are presented in more detail in Appendix B.[18]

We then phase in GridWise over 20 years, beginning in 2006,[19] and compare the results with those from the AEO 2003 baseline. To explore the sensitivity of benefits to the input data and assumptions, we develop a series of scenarios representing different, but plausible, development paths for GridWise. Benefits for each scenario are calculated as the present value over 20 years of the cash flow differences from the AEO 2003 baseline projections.

Table 3.1

System Generating Capacity and Peak Demand, Without GridWise

	Year			
	2003	**2010**	**2015**	**2025**
Net summer generating capacity (GW)	911	925	1,006	1,174
Noncoincident peak demand (GW)	705	786	855	998
Generating reserve margin (%)	22	15	15	15
Average capacity factor (%)	47	53	53	53

SOURCES: EIA 2003, Tables 8 and 9; EIA 2001, Table 3.3.

[17] These estimates represent gross benefits that do not include GridWise R&D and implementation costs. Net benefits, including such costs, will be estimated in Phase II.

[18] Estimates of U.S. noncoincident peak load without GridWise, derived from Table 3.3 of the most recent *Electric Power Annual* (EIA 2001), also are part of the baseline projections shown in Tables 3.1 and 3.2 and in Appendix B.

[19] The estimates assume that GridWise implementation and resulting benefits begin no earlier than 2006.

Table 3.2

Electricity Consumption and Expenditure, by End-User Sector, Without GridWise

	Year			
	2003	2010	2015	2025
Electricity sales (billion kWh)				
Residential	1,279	1,445	1,539	1,742
Commercial	1,248	1,471	1,640	2,003
Industrial and transportation	1,000	1,184	1,302	1,466
Total	3,527	4,100	4,481	5,253
Average price (2001 cents/kWh)				
Residential	7.9	7.6	7.7	7.9
Commercial	7.1	6.7	6.9	7.3
Industrial and transportation	4.5	4.4	4.5	4.7
All end-users	6.6	6.4	6.5	6.7
Price by service category (2001 cents/kWh)				
Generation	4.2	3.8	3.9	4.2
Transmission	0.5	0.6	0.6	0.6
Distribution	2.0	2.0	1.9	1.9
Electricity expenditure (billion 2001 $)				
Residential	101	110	119	138
Commercial	89	99	113	146
Industrial and transportation	45	52	58	70
Total	234	260	290	354

SOURCE: EIA 2003, Table 8.

System Benefits from GridWise-Enabled Demand Response

Price-responsive demand enabled by the widespread availability of dynamic prices is at the core of our framework for estimating GridWise benefits. This section provides a simplified overview of how demand response leads to final benefits for the electricity system as a whole, as well as to suppliers and end-users. The economic principles underlying transfers of benefits among suppliers and end-users are discussed further in Appendix A.[20]

[20] For an introduction to the economic and policy issues surrounding demand response and dynamic pricing, see Rosenfeld, Jaske, and Borenstein, 2002. Other pertinent publications include Braithwait et al., 2002; Crew et al., 1995; Faruqui and George, 2002; Gulen and Foss, 2002; King and Chatterjee, 2003; and Smith and Kiesling, 2003. Additional references are listed in Louie, 2002.

Microeconomic Framework for Demand Response Estimates

Electricity supply and demand without GridWise are shown schematically in Figure 3.1. In this simplified depiction, end-users pay a fixed retail price (RP) for energy at all times, independent of the actual supply cost curve that determines the wholesale market-clearing price for bulk power sales. End-user demand at peak and off-peak periods is inelastic, that is, unresponsive to price, as represented by the vertical lines at Q_P and Q_O, respectively. Off-peak, the wholesale price WP_O (determined by the intersection of the supply curve with off-peak demand Q_O) lies below the retail price, providing a fair return to distribution utilities. But when retail demand increases at peak periods, the peak wholesale price WP_P (determined by the intersection of the supply curve with peak demand Q_P) can rise well above the fixed retail price.

From an economic perspective, fixed retail prices and inelastic demand mean that wholesale and retail markets are disconnected. End-users consume too much electricity at high-cost peak periods and too little during low-cost off-peak periods than is socially efficient.[21]

When GridWise is implemented (Figure 3.2), end-users are charged prices that reflect underlying supply costs. If they have the technical means to change their power consumption in line with their price sensitivity (elasticity), then their demand changes from a vertical line to the downward-sloping curve in Figure 3.2. At peak times, end-users see higher prices than before; hence, their peak consumption (represented by the intersection of the peak demand curve with the supply curve) decreases, which in turn reduces the peak wholesale price below its pre-GridWise level.[22]

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[21] See the discussion in Appendix A.

[22] How far the peak wholesale price drops depends on the shape of the supply curve, which typically becomes much steeper at peak demand levels. Consequently, a small percentage decrease in peak demand can produce a larger drop in the peak wholesale price. The new peak wholesale price $WP_{P,GW} = (WP_P \eta_s + RP\ \eta_d)/(\eta_s + \eta_d)$, where WP_P is the old peak wholesale price, RP is the old retail price, and η_s and η_d are the price elasticities of supply and demand, respectively. Recent estimates of the price elasticity of supply range from 0.1 to 0.2 during the highest peak hour to around 1.0 over the summer peak season as a whole (Faruqui et al., 2002; Braithwait and Faruqui, 2001).

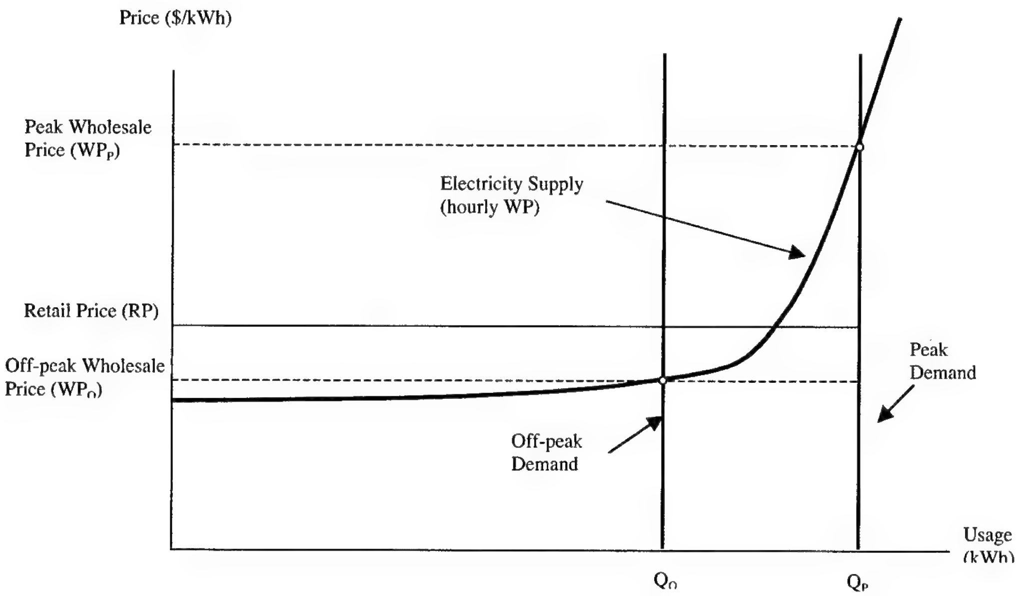

Figure 3.1. Electricity Market with Inelastic Demand, Pre-GridWise

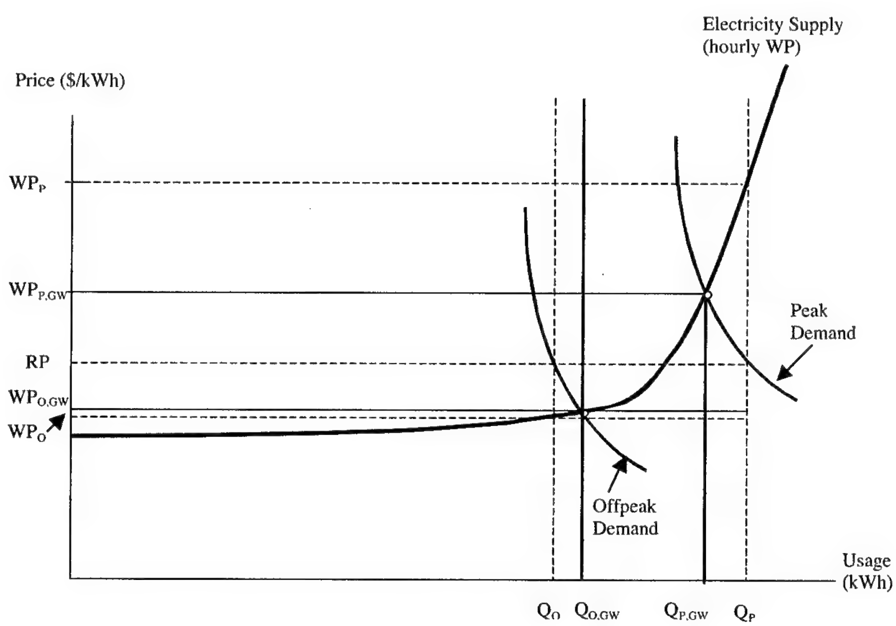

Figure 3.2. Electricity Market with GridWise-Enabled Demand Response

Off-peak consumption increases with GridWise, both because end-users see lower off-peak prices than before[23] and because some of the drop in peak consumption represents a shift of usage to off-peak periods.[24]

Linking Demand Response to System Capacity Decisions

Lower peak demand means that, in principle, the system can reduce peak generating capacity commensurately. However, this does not necessarily mean that existing generating plants will be taken offline, since the AEO 2003 baseline projections show overall demand growing steadily through 2025. In our model, the system first adjusts to lower peak demand by deferring construction of new peak-load plants (primarily gas-fired combustion turbine or diesel generators) that would otherwise be built to serve projected growth. If necessary, intermediate-load plants (primarily gas-fired combined cycle) are also deferred. The secular growth in off-peak demand[25] is accommodated by higher capacity factors in already-built generation plants, as well as by new baseload (primarily coal-fired) and intermediate (gas-fired combined cycle) capacity contained in the AEO 2003 projections.[26]

Paralleling the implementation of demand response, GridWise enables the use of load and distributed resources as system reserves. This permits the system to reduce generating reserve margins, thereby further deferring construction of some planned new generation capacity.

Reduced peak demand and lower generating reserve margins also mean that less new transmission and distribution capacity needs to be built. Following Hirst and Kirby (2001), our model estimates transmission capacity deferral as a function of generation capacity deferral. Distribution capacity deferral follows the reduction of peak-load growth from the AEO 2003 baseline. Distribution plant investment is both variable and lumpy in any particular geographic service area; but taking a national perspective smooths out most of the variability and lumpiness, so that new distribution investment can be modeled as linearly tracking the growth in peak demand.

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[23] As shown in Figure 3.2, the new off-peak price $WP_{O,GW}$ is slightly above the old offpeak price WP_R but well below the old retail price RP.

[24] See Caves and Christensen, 1980a, for a discussion of substituting off-peak for peak power consumption. Based on PJM data for 2000, McKinsey & Company, 2001, assume that slightly over half of the peak-load reduction from demand response would be shifted to off-peak.

[25] Including the load shifted from peak to off-peak.

[26] Projected capacity additions come from AEO 2003, Table 9; capital, O&M, and fuel costs for these plants are taken from the AEO 2003 assumptions, Table 40. Details are given in Appendix B.

Estimates of System Benefits from the Demand Response Model

For the 20 years in which GridWise is assumed to be implemented (2006–2025), the demand response model first calculates peak-load reduction and then the resulting generation, transmission, and distribution capital cost deferrals. It then computes the capital cost deferrals resulting from lower generating reserve margins. Deferring new capacity also implies deferring or reducing associated operating and fuel costs.[27]

The model calculates peak-load reductions based on a 20-year growth of GridWise adoption in the residential, commercial, and industrial sectors.[28] By adoption, we mean the actual use of smart meters, real-time prices, and other changes that GridWise enables. Experience to date indicates that there may be a considerable lag between market introduction and adoption and that some end-users, particularly residential and small-business end-users, may choose not to use real-time pricing even if it appears financially advantageous for them to do so.[29]

Consequently, the model includes parameters for both market penetration (i.e., the percentage of end-users who adopt GridWise-enabled demand response) and price elasticity of demand (i.e., the price responsiveness of those who do adopt), by end-user sector. Other important inputs to the model include wholesale peak and off-peak prices without GridWise, the percentage of peak-load reduction that is shifted to off-peak, the projected generating reserve margin in 2025, and the discount rate for computing benefit present values. Table 3.3 lists these input variables and our estimates of the range of plausible values for them, based on prior studies and our own judgment.

Table 3.3 also lists the inputs for an initial, "nominal" scenario based on what we consider midrange estimates of GridWise market penetration, demand, and supply elasticities and other variables. The results from the nominal scenario

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[27] The changes in operating and fuel costs must again take into account shifting of some peak load (served primarily by combustion turbine and diesel generators) to off-peak (served primarily by coal and gas-fired combined cycle plants).

[28] To simplify the calculations, the transportation sector is merged with the industrial sector, since transportation accounts for well under 1 percent of purchased electricity.

[29] "When we listen to customers discuss what they need and what is important to them, we find RTP [real-time pricing] is seldom a good fit. In fact, most customers are willing to pay a premium over RTP for more simplicity and certainty in their pricing" (EnerVision, 1998). Similarly, an EPRI-sponsored survey conducted by Primen during August-September 2003 finds that "while about half of respondents said keeping energy costs down was a major issue, very few expressed an interest in innovative pricing programs or energy information services that might help them achieve that goal.... Utilities should not underestimate the amount of education that will be required for business customers to understand the value and benefit of services like demand response or flexible pricing" (EPRI, 2003c).

Table 3.3

Principal Input Variables and Range of Plausible Values, Demand Response

Input Variable	Low Value	Nominal Scenario	High Value	References
2025 market penetration: residential (percent)	15	40	67	
2025 market penetration: commercial and industrial (percent)	40	70	90	
Price elasticity of demand: residential	0	-0.15	-0.5	Faruqui and George, 2003; Caves and Christensen, 1980b
Price elasticity of demand: commercial and industrial	-0.1	-0.2	-1.0	King and Chatterjee, 2003
Price elasticity of supply	0.1	1	2	Faruqui et al., 2002; Braithwait and Faruqui, 2002
Wholesale peak price without GridWise (c/kWh)	7.5	9.0	100	Based on PJM, 2003
Peak percentage of total kWh without GridWise	1	10	15	Based on PJM, 2003
Percentage of peak reduction shifted to off-peak	20	50	80	McKinsey, 2001; Caves and Christensen, 1980a
2025 generating reserve margin (percent)	5	12	15	Kannberg et al., 2003; NERC, 2002
End-user share of total system benefits (percent)	20	40	75	
Number of years for GridWise implementation	12	20	30	
Capital cost (2001 $/KW)				See Appendix B
Gas turbine/diesel gen.	400	460	600	EIA 2003, Table 40
Gas combined cycle gen.	500	608	1200	EIA 2003, Table 40
Transmission plant	125	143	200	EEI 2003; Hirst and Kirby, 2001
Distribution plant	250	300	700	Shirley, 2001

are given in Table 3.4, and the calculations leading to them are presented in greater detail in Appendix D.

In the nominal scenario, demand response reduces peak load 9.5 percent by 2025 and results in capital and operating cost savings to the electricity system totaling $139 billion through 2025. If a 10 percent real discount rate is used,[30] the present

[30] A 10 percent real discount rate is plausible for GridWise, which incorporates many different types of investments, each with different risks. Ibbotson Associates, 2001, estimated the nominal weighted average cost of capital for electric T&D equipment as of March 31, 2001, to be 13 percent,

Table 3.4

System Capacity and Cost Deferrals, Nominal Scenario

	Year			Present Value in
	2010	2015	2025	2006–2025
Peak-load reduction (percent)	2.9	5.3	9.5	na
Deferred generation capacity[a] (GW)				
From reduced peak load	26	53	107	na
From lower reserve margin	8	17	36	na
Deferred capital costs[a] ($ billions)				
Generation	22	41	79	33
Transmission	6	11	21	9
Distribution	7	13	27	12
Reduced O&M, fuel costs[a] ($ billions)	—	4	12	4
Total system cost savings[a] ($ billions)	35	69	139	57

[a] Cumulative through year shown.

value of these savings is $57 billion.[31] Using a 6 percent real discount rate would increase the present value to $78 billion.

We next use the 20-year present value of system cost savings as the primary measure with which to compare system benefits from demand response among five different scenarios:

1. The **nominal scenario** as described above.

2. **Highly competitive and responsive markets** with high GridWise market penetration and high demand response. In this scenario, GridWise market penetration after 20 years is 67 percent for residential end-users and 90 percent for commercial and industrial end-users; price elasticities of demand are –0.20 for residential end-users and –0.25 for commercial and industrial end-users; and the generating reserve margin has been reduced to 9 percent.

3. **Less competitive and responsive markets** with lower GridWise market penetration and demand response. After 20 years, GridWise market penetration is only 20 percent for residential end-users and 50 percent for commercial and industrial end-users; price elasticities of demand are

which approximates a 10 percent real rate. For more risky R&D investments, the rate would be higher. The U.S. Office of Management and Budget specifies a discount rate of 3.2 percent for 30-year federal government investments that provide benefits primarily to government and a discount rate of 7 percent for federal investments that provide external social benefits (OMB 2003, p. 9). Kannberg et al., 2003, use a 6 percent discount rate.

[31] Unless otherwise indicated, benefits are in 2001 dollars, and present values are based on cash flows over the 20 years from 2006 to 2025.

–0.10 for all end-users; and the generating reserve margin remains at 15 percent.

4. **Lower generating reserve margin of 6 percent** in 2025. Other assumptions are the same as in the nominal scenario.

5. **Real discount rate of 6 percent in 2025.** Other assumptions are the same as in the nominal scenario.

The estimated system benefits in terms of peak-load reduction, deferred generating capacity, and 20-year present values of system cost savings are compared in Table 3.5. Figure 3.3 graphically presents the present-value comparisons. The wide range of present-value estimates, from $16 billion to $95 billion, indicates how sensitive the system cost savings are to the input variables, in particular, to the assumed values in 2025 for GridWise market penetration, generating reserve margins, and demand elasticities.

Benefits from Improved Power Quality and Reliability

The August 2003 EPRI *Framework for the Future* report estimated that the economic losses to U.S. businesses from power outages and disturbances are "in the range of ... $100 billion per year" and that costs may increase "by as much as

Table 3.5

System Benefits Resulting from Demand Response, by Scenario

	Scenario				
	Nominal	**High Market Response**	**Low Market Response**	**6% Gen. Reserve Margin**	**6% Discount Rate**
Peak-load reduction in 2025 (percent)	9.5	16.4	3.5	9.5	9.5
Deferred generation by 2025 (GW)					
From reduced peak load	107	169	40	107	107
From lower reserve margin	36	66	0	102	36
Present value (billions of 2001 $)					
Deferred capital costs					
Generation	33	57	8	50	45
Transmission	9	14	3	12	12
Distribution	12	18	4	12	16
Reduced O&M, fuel costs	4	6	1	4	6
Total system cost savings	57	95	16	77	78

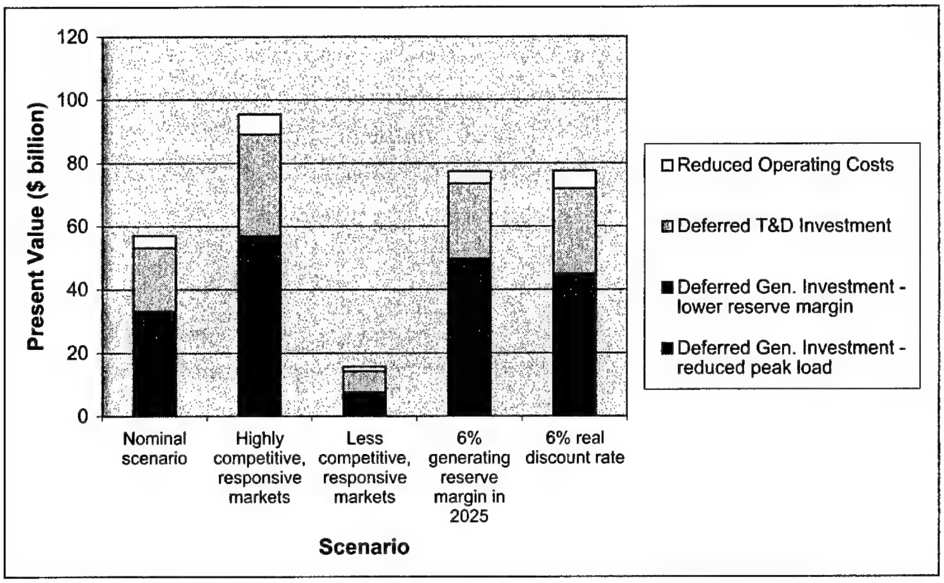

Figure 3.3. System Benefits Resulting from Demand Response, by Scenario

an additional $100 billion per year over a twenty-year period."[32] The blackouts that affected much of the northeastern United States on August 14, 2003, further reinforce concerns over the reliability and vulnerability of the U.S. electricity T&D infrastructure. Consequently, to the extent that GridWise can contribute to improving overall power quality and reliability (PQR), as well as to the security of the electricity infrastructure, the benefits can be substantial.

In this section, we estimate those benefits based on (1) estimates of GridWise efficacy in avoiding or reducing economic losses from power outages and disturbances[33] and (2) projections of such losses through 2025.

GridWise Impact on Power Outages and Disturbances

Power outages and disturbances come in many forms. Outages—that is, more than momentary interruptions of power availability—affect all residential and business customers with loads comprising primarily space conditioning, lighting, water heating, conventional appliances, motor-generators, and other analog equipment. But computing equipment and related digital loads are also

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[32] EPRI, 2003b, Vol. I, 40. This report summarizes other EPRI studies over the past few years that find similar results, such as EPRI 2001a, EPRI 2001b, EPRI 2001c, and EPRI, 2002.

[33] Improved PQR may also enable firms to improve their production and business processes, another benefit that we discuss but do not estimate in Chapter 4.

adversely affected by even momentary interruptions, as well as by surges, sags, spikes, impulses, and other irregularities in the normal electrical waveform. These disturbances occur much more frequently than do actual outages.[34]

Eighty to 90 percent of end-user outages can be traced to problems in the distribution system,[35] most of which are caused by equipment malfunctions (e.g., a transformer failure) or physical damage to distribution plants (e.g., a tree branch falling on a power line). Transmission line problems account for only 10 to 20 percent of outages, but these include the largest and most costly events, including the August 14, 2003, blackout. Widespread outages often start as localized peak overload conditions that propagate through the transmission system, as occurred on August 14. In general, increased transmission line congestion adds to the risks of local system overloading that can escalate into large-scale outages.[36]

GridWise addresses transmission congestion issues on the demand side through demand response and controllable load. GridWise-enabled distributed controls and improved diagnostic tools within the transmission system also help dynamically balance electricity supply and demand. Consequently, GridWise should be most effective in helping the system respond to supply/demand imbalances and in limiting their propagation if and when they occur. This could substantially reduce the frequency of outages and power disturbances due to grid overloading and could also avoid the kind of "planned" rolling blackouts and brownouts that were imposed by California's independent system operator (ISO) when peak demand exceeded available supply during the summer of 2000.

GridWise should also help mitigate the consequences of weather-related outages and other physical damage to transmission and distribution facilities, primarily through better diagnostics and controls that can isolate problems and direct crews to repair them, but the potential impacts here appear to be smaller than those for outages related to system overloading.

Overall, we project that GridWise will have greater impact on transmission-related than on distribution-related outages and disturbances. In the nominal scenario, we assume that, where implemented, GridWise will reduce transmission-related outages by 33 percent and distribution-related outages by

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[34] Outages represent only 5 to 10 percent of all disturbance events, according to Scheinbein and DeSteese, 2002, and EPRI, 2002.

[35] EPRI, 2001c; EEI, 2001.

[36] The 2002 National Transmission Grid Study (DOE, 2002) discusses congestion problems facing the U.S. transmission grid. See also Carreras et al., 2003, for a discussion of transmission outage issues.

20 percent (Table 3.6). A high-PQR-impact scenario, which is consistent with the assumptions in Kannberg et al., 2003, and EPRI, 2001c, assumes 50 and 33 percent reductions in transmission- and distribution-related outages, respectively. Conversely, a low-PQR-impact scenario assumes reductions of 20 and 10 percent, respectively. Although none of these assumptions is well grounded in empirical evidence, they span, in our view, a plausible range of expected impacts of GridWise on power quality and reliability.[37]

Current and Projected Costs of Power Outages and Disturbances

As stated in the EPRI "Framework for the Future" report, "Data on the economic impact of power outages and disturbances are difficult to obtain."[38] The cost to

Table 3.6

Principal Input Variables and Range of Plausible Values, Power Quality and Reliability

Input Variable	Low Value	Nominal Scenario	High Value	References
Average cost of outages to user ($/kWh lost):				Balducci et al., 2002; Willis and Scott, 2000; Hunter et al., 2003; IEEE, 1997; EPRI, 2001a, 2002
Residential	0.15	2	10	
Commercial	10	25	40	
Industrial	7	15	40	
Annual cost of outages to U.S. economy in 2003 ($ billions)	30	50	120	EPRI, 2003b (high value)
Transmission outages as a percentage of total outages	8	20	25	EPRI, 2001c; EEI, 2001
GridWise implementation in T&D grid by 2025 (percent)				
Transmission	25	50	80	Kannberg et al., 2003;
Distribution	15	25	50	EPRI, 2001c
Outages reduced with GridWise implementation (percent)				
Transmission	20	33	50	Kannberg et al., 2003;
Distribution	10	20	33	EPRI, 2001c

[37] Numerous other studies, including Arthur D. Little, 1999a and 1999b, and studies cited in Iannucci et al., 2003, point to the role of DER in improving power quality and reliability. The GridWise concept embraces more rapid growth of DER than is represented in the AEO 2003 baseline projections, which implies benefits from reduced outages and disturbances. In this Phase I report, the PQR benefits of GridWise-enabled DER are included in the assumptions in Table 3.6 about GridWise efficacy. We expect to estimate those DER benefits separately in Phase II.

[38] EPRI, 2003b, Vol. I, 40. Eto et al., 2001, reach a similar conclusion.

an individual end-user depends on the severity of the outage or disturbance, the value of the electrical services forgone, the cost of interrupted production processes, the cost of alternative power sources and other means to avoid or mitigate outage losses, and/or the cost of insurance to recover the losses.

Table 3.6 presents a range of estimated costs of power interruptions in the commercial, industrial, and residential sectors, based largely on the excellent summary of prior estimates reported in Balducci et al., 2002.[39] For the nominal scenario, multiplying the cost per kWh for each sector by the estimated kWh undelivered, assuming 99.9 percent grid reliability, conservatively puts the total cost of outages to end-users in 2003 at $49 billion. In contrast, a considerably higher estimate of $120 billion is reported in EPRI, 2003b, based on the results of a survey of costs to firms in sectors particularly sensitive to power reliability that are then discounted to include other sectors of the U.S. economy.

For the nominal scenario, the 20-year present value of end-user savings from reduced outages and disturbances is $15 billion,[40] as shown in Table 3.7 and presented in greater detail in Appendix D. Present values for high and low

Table 3.7

End-User Benefits from Improved Power Quality and Reliability, by Scenario

	Scenario		
	Nominal	**High GridWise Impact on PQR**	**Low GridWise Impact on PQR**
Cost of outages in 2003 ($ billions)	50	100	50
GridWise implementation in 2025 (percent)			
Transmission plant	50	60	40
Distribution plant	25	30	20
Outages reduced with GridWise (percent)			
Transmission-related	33	50	20
Distribution-related	20	33	10
Present value of savings ($ billions)	15	49	5

39 For simplicity, costs are shown per kWh undelivered, although many of the estimates documented in Balducci et al., 2002, and in IEEE, 1997, have both capacity (kW) and energy (kWh) components.

40 Transmission and distribution plant owners and operators also benefit from fewer outages and disturbances by recouping previously lost revenue from undelivered power and reducing their outage-related maintenance and repair expenses. The present values of these supplier benefits are less than $1 billion in all of our scenarios, however, and are not considered further in this analysis.

GridWise impacts on PQR are $49 billion and $8 billion, respectively. Even higher or lower present values can easily be obtained by further varying GridWise efficacy in reducing outages or disturbances, the GridWise implementation time or scope, or the discount rate. The large variation in results indicates both the sensitivity of these calculations to the input variables and the lack of good empirical data on outage costs or GridWise efficacy that could narrow the range of plausible input values.

End-User Benefits from Improved Efficiency

GridWise-enabled diagnostic, monitoring, and control technologies can make end-user electricity use more efficient in many ways that lead to cost savings. The savings from peak-load reduction and load shifting are already included in the demand response framework. In this section, we estimate the additional benefits that are not peak-related, namely, those resulting from more efficient electricity use in buildings during off-peak periods.

GridWise technologies will be applied primarily to improve the energy management systems (EMSs) that building owners and tenants use to control heating, ventilation, and air conditioning (HVAC) and lighting. According to the AEO 2003 estimates, HVAC and lighting constitute 40, 38, and 15 percent of total electricity use in the residential, commercial, and industrial sectors, respectively (see Table 3.8).

Following Rabaey et al., 2001, we distinguish three levels of EMS development that use increasingly sophisticated information and network technologies:[41]

- Level 1 EMSs involve largely passive monitoring of data from various sensors about local conditions (temperature, lighting, equipment usage) and use simple devices such as timers or thermostats to make control decisions.
- Level 2 EMSs include electricity prices in addition to other sensor data that are fed to a centralized, programmable controller.
- Level 3 EMSs actively manage energy use, with distributed sensors gathering local and external data and distributed control units applying the building owner's programmed rules and preferences. Level 3 embodies the "smart building" concept that has been demonstrated and widely publicized but not yet widely deployed.

[41] See Baer, Hassell, and Vollaard, 2002, pp. 43–46, for further discussion of these three levels of EMS development.

Table 3.8

Principal Input Variables and Range of Plausible Values for Energy Efficiency (percent)

Input Variable	Low Value	Nominal Scenario	High Value	References
2003 HVAC, lighting (percent of total electricity use)				EIA, 2003, Tables 4, 5, 6
Residential	40	40	40	
Commercial	38	38	38	
Industrial	15	15	15	
Incremental electricity savings with Phase 3 EMS				Baer, Hassell, and Vollaard, 2002
Residential	5	6	8	
Commercial	6	8	10	
Industrial	6	8	10	
Level 3 EMS market penetration in 2025				
Residential	15	30	50	
Commercial	30	50	80	
Industrial	30	50	80	

Levels 1 and 2 represent pre-GridWise forms of EMS whose savings are part of the baseline projections. Only the incremental electricity savings from Level 3 EMS, shown in Table 3.8, are considered GridWise-enabled. Table 3.8 also shows the projected market penetrations of Level 3 EMS in 2025 for the nominal scenario as well as for high- and low-penetration scenarios.

For the nominal scenario, the 20-year present value of incremental end-user savings from Level 3 energy management systems in buildings is $9 billion, as shown in Table 3.9 and presented in greater detail in Appendix D. Present values for the high and low cases are $18 billion and $4 billion, respectively.

Table 3.9

End-User Benefits from Level 3 EMS Efficiency, by Scenario

	Scenario		
Incremental Savings in 2025	Nominal	High GridWise Impact	Low GridWise Impact
Electricity consumption (billion kWh)	52	106	23
Electricity expenditures ($ billions)	3	7	1.5
20-year present value ($ billions)	9	18	4

Preliminary Estimates of Benefits

We can now estimate the overall benefits to electricity system suppliers and end-users from GridWise-enabled peak-load reduction, reduced generating reserve margins, improved power quality and reliability, and improved energy efficiency in buildings. Figure 3.4 displays these present-value benefits for the nominal scenario and four other scenarios whose input variables differ from those in the nominal scenario as follows:

- **Highly competitive and responsive markets** with higher values for GridWise market penetration among end-users, demand response, use of advanced EMS, impact on generating reserve margins, electricity market competitiveness, and T&D implementation to improve power quality and reliability.
- **Less competitive and responsive markets** with lower values for GridWise market penetration among end-users, demand response, use of advanced EMS, impact on generating reserve margins, electricity market competitiveness, and T&D implementation to improve power quality and reliability.

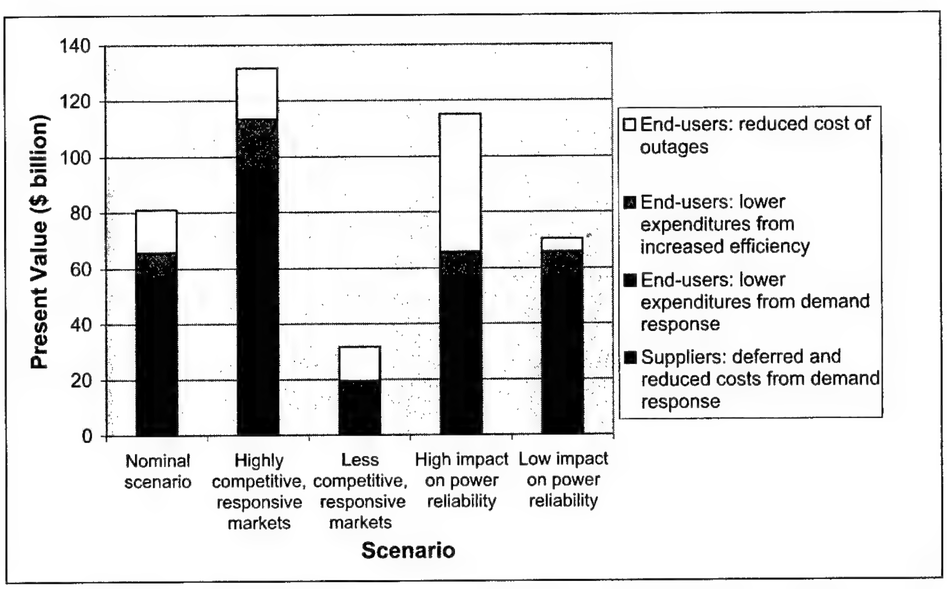

Figure 3.4. Supplier and End-User Benefits from GridWise, by Scenario

- **High PQR impact** with higher costs to end-users pre-GridWise and greater GridWise efficacy in reducing outages and disturbances.
- **Low PQR impact** with less GridWise efficacy in reducing outages and disturbances.

The numerical results of these benefit calculations are given in Appendix C, along with a comparison of the important input variables for each scenario.

The first three scenarios in Figure 3.4—nominal, highly competitive and responsive markets, and less competitive and responsive markets—correspond to those in Figure 3.3 that showed system savings from demand response. These system benefits accrue partly to industry suppliers (the bottom segment of each bar) and partly to end-users (the next segment of each bar). The split depends largely on the extent of market competitiveness and responsiveness. In the nominal scenario, end-users receive 40 percent of system savings from demand response, passed on primarily as lower off-peak prices that result in lower total expenditures for power. Suppliers receive the rest, benefiting from deferred and reduced costs that substantially outweigh the impact of lower end-user spending.[42] Including benefits from EMS efficiencies and improved PQR brings the total present value of benefits to suppliers and end-users to $81 billion.

When electricity markets are both highly competitive and responsive, end-users receive an even larger share (60 percent); but the total system benefits are greater, so the industry suppliers receive large benefits, too. Total benefits, including EMS efficiencies and improved PQR, rise to $132 billion. In the less competitive and responsive market scenario, suppliers get most of the system benefits (75 percent), but there is considerably less to divide. Total benefits including EMS efficiencies and improved PQR are only $32 billion, $100 billion less than those for the highly competitive and responsive scenario.

The last two scenarios in Figure 3.4, where GridWise has high and low impact on power quality and reliability, yield total benefits of $115 billion and $70 billion, respectively.

[42] Of course, not all suppliers will gain equally. Baseload and some intermediate-load generators will benefit from higher capacity factors as some load shifts from peak to off-peak, but some owners of peak generating plants will likely see their cash flows and profits decline. The estimates shown here are for all electricity suppliers and are not disaggregated by type, fuel, or region.

4. Discussion

The results in Figure 3.4 clearly show that the estimated benefits from GridWise can be quite large, exceeding $100 billion in two of the five scenarios. However, the variance among estimates is also very large, depending, of course, on the input data and assumptions. At this early stage of GridWise development, many of the input variables and projections are highly uncertain. Consequently, we believe that delineating the range of benefits based on plausible input variables is more useful than trying to converge on a single "best estimate."

Comparison with Other Estimates of Benefits

Estimates of GridWise benefits recently published by PNNL (Kannberg et al., 2003) are the most directly comparable to our results. The 20-year present value of benefits for the PNNL "conservative" scenario totals $75 billion (Figure 4.1), which initially appears close to the $81 billion present value for our nominal scenario. However, the PNNL present values are based on a 6 percent discount rate, compared with the 10 percent rate used in our nominal scenario; with a 6 percent discount rate, the present-value estimate for our nominal scenario would rise to $110 billion. The difference between the $110 billion and $75 billion estimates primarily reflects the fact that our nominal scenario is intended to be more "midrange" than "conservative."

The benefit components in the PNNL estimates are similar to those in our estimates, although the approaches to calculating system capacity and operating cost savings differ considerably. In particular, our estimates of system cost savings include not only deferred capacity additions but also the capacity factor and ancillary services benefits estimated separately in Kannberg et al., 2003 (p. 25) and shown in Figure 4.1.[43]

One notable difference between the PNNL estimates and our estimates is that we do not include a quantifiable benefit from lowered cost of capital for new generation investments, whereas PNNL does. The rationale for such an "avoided

[43] In our model, as discussed in Chapter 3, total system benefits from demand response accrue partly to suppliers as reduced costs and partly to end-users as reduced expenditures. Kannberg et al., 2003 (pp. 20–21) evaluate the effect of demand response on expenditures but do not include the results in their conservative scenario "because of the wide range of these estimates and the fact that they possibly may embed, at least in part, other benefits already counted."

capital risk benefit" is that flattening the load curve through GridWise stabilizes generating plant costs while increasing their capacity factors and hence their revenues and cash flows. With larger and more stable projected cash flows provided by GridWise, new generating plants will be less risky investments, enabling their owners to borrow money at lower rates than before. Kannberg et al., 2003 (p. 16) estimate that the borrowing rate will be 1 percent lower, resulting in a 20-year present-value benefit of $11 billion.

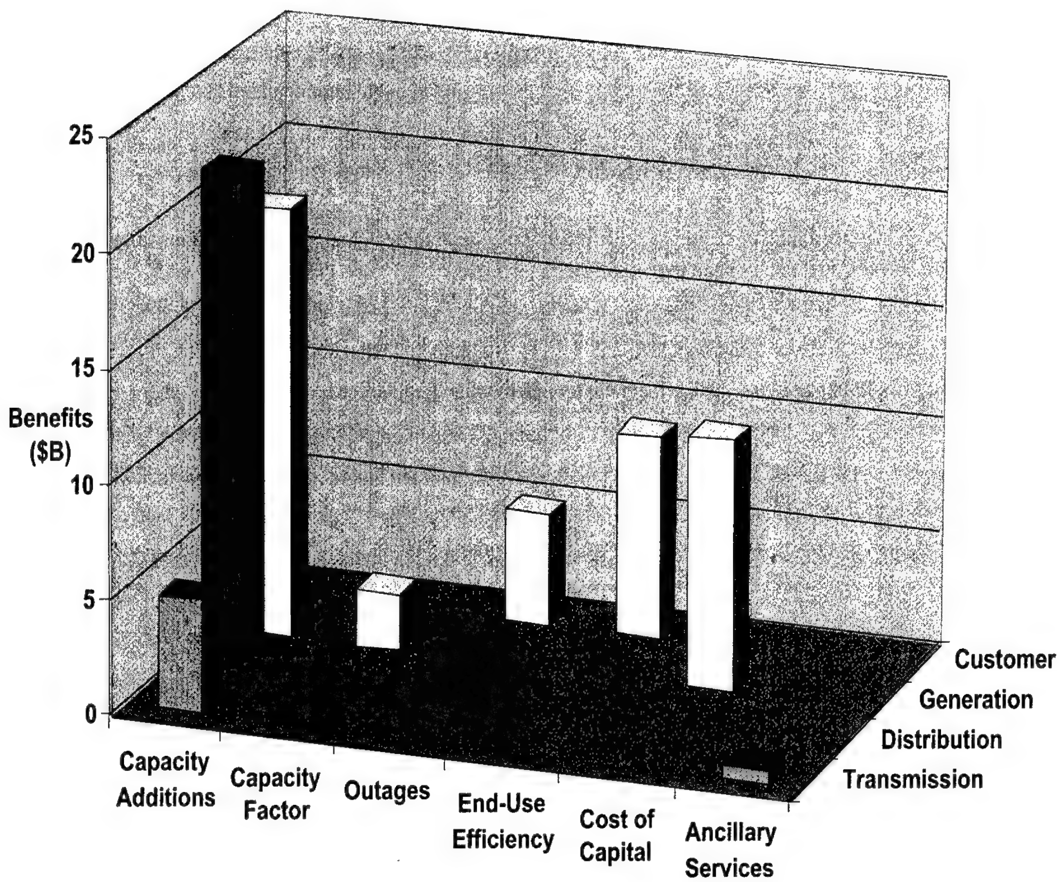

Figure 4.1. GridWise Benefits for a Conservative Scenario, from Kannberg et al., 2003

While this rationale has merit, we believe there are several contending factors that argue against a significant "avoided capital risk benefit" for new generating plants over the 20-year period used to estimate benefits:

- According to the AEO 2003 projections shown in Appendix B, more than 75 percent of new generation capacity through 2025 will be load-following peak and intermediate plants rather than baseload plants. The implementation of GridWise will bring continuing reductions in peak loads throughout this period (compared with those projected in AEO 2003), but the size and timing of the reductions will be somewhat uncertain. This is very likely to make the financing of load-following plants more risky rather than less. Put another way, lenders may want to add a risk premium on their loans to load-following plants to compensate for uncertain future reductions in peak demand. On the other hand, loans to new baseload plants with higher anticipated capacity factors could well be made at lower rates. And once the GridWise transition is complete, stable load patterns could indeed lead to lower financing costs for the entire generating sector.
- Most of our scenarios assume that the generating sector will become more competitive over the next 20 years, in good part due to more efficient markets for electricity enabled by GridWise. New investments are generally riskier in a less-regulated, competitive market than under the rate-of-return regulation that previously characterized the generating sector. Thus, other things being equal, we would expect the average cost of financing new generating plants to increase rather than decrease as the sector becomes more competitive and less regulated.
- Volatility of future gas prices will likely add risk to the financing of gas-fired peak and intermediate (combined cycle) generating plants, and GridWise is not expected to affect gas price volatility. AEO 2003 (p. 68) projects that gas-fired plants will dominate generation investment through 2025.

We would expect that the reduced peak load and greater system stability enabled by GridWise will reduce financing costs for investments in transmission and distribution more than in generation. Financing costs for distributed generation plants should also be favorably impacted, since GridWise encourages DER integration with the grid and generally improves DER economics.[44] On balance, however, given the conflicting trends and factors discussed above, we cannot estimate with confidence either the direction or the magnitude of the effects of

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[44] See the brief discussion of avoided capital risk benefits for distributed generation in Kannberg et al., 2003, p. 16.

GridWise on financing costs for new electricity infrastructure. We thus have not made any such estimates in these Phase I results, but we plan to revisit the topic in Phase II.

A 2001 McKinsey & Company White Paper estimated annual savings of $10 billion to $15 billion from implementing demand response with real-time pricing nationally (McKinsey, 2001, p. 4). While the White Paper does not explicitly state what percentage of end-users respond, the estimated savings seem consistent with our estimate in the high-response scenario of annual savings in the 20th year of $9 billion, with 67 percent of residential end-users and 90 percent of commercial and industrial end-users participating.

Finally, our estimates of benefits from GridWise-enabled improvements in power quality and reliability are much lower than those reported in the EPRI *Electricity Sector Framework for the Future* report (EPRI, 2003b, Vol. 1, pp. 39–44). Our high-PQR-impact scenario projects annual benefits of $18 billion after 20 years, compared with $100 billion to $175 billion in the EPRI report. The much larger EPRI figure reflects both greater projected costs of outages and disturbances after 20 years without systemic changes and greater efficacy in reducing those costs through technology improvements in the T&D grid.[45]

Benefits Not Included in Phase I Estimates

As noted above, our Phase I estimates do not include the potentially lower costs of financing new generation and other infrastructure investments. Several other categories of possible GridWise benefits are also not included, e.g.:

- Integration of distributed energy resources with the grid.
- Reduced emissions and other environmental externalities.
- Intangible benefits.
- End-user productivity gains.

[45] Table 5.1 in EPRI, 2003b, Vol. 1, p. 42, projects an 87 percent reduction in the annual cost of power disturbances to businesses by 2020 for an "enhanced productivity" scenario, compared with our projections in the high-PQR-impact scenario of 50 percent and 33 percent reductions, respectively, for transmission-related and distribution-related disturbances.

Based on our preliminary analysis, benefits in the first two categories listed above appear to have relatively small present values compared with those estimated in Chapter 3. The latter two categories could conceivably yield much larger benefits, but those benefits depend on assumptions that at this point seem very difficult to validate.

For distributed energy resources, Iannucci et al., 2003, list 13 categories of benefits addressed in 31 key studies.[46] The most frequently cited categories with the largest prospective benefits are capacity deferrals (distribution, transmission, and generation),[47] energy savings, and reliability enhancement.[48] As previously noted, GridWise would reduce the costs of interconnecting DER with the grid and would generally improve DER economics.[49] GridWise should thus accelerate DER growth, with its resulting benefits. However, even with optimistic assumptions about future DER growth,[50] the capacity deferral and energy savings benefits appear limited. Assuming that as a result of GridWise, DER capacity through 2025 grows twice as fast as is projected in AEO 2003, our preliminary estimates show the resulting benefits from T&D capacity deferrals and energy savings to have a 20-year present value of only $1 billion to $1.5 billion. While the reliability benefits from accelerated DER could be greater, they are already included in the estimated benefits from improved PQR in Chapter 3.[51]

Similarly, our preliminary estimate of the present value of benefits from reduced emissions due to GridWise appears to be no greater than $1 billion, counting emissions benefits both from less power consumed and from fewer startups of centralized generating plants to serve peak loads. The net effect on emissions of more DER generation depends on the emission profiles and duty cycles of the specific DER mix and could be negative.

As indicated in Chapter 2, we have not attempted to estimate intangible benefits from GridWise, such as greater public confidence in the electricity system or some other potential benefits listed in Table 2.1. Lovins et al., 2002, list but do not quantify a variety of projected intangible benefits that relate to substituting DER

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[46] See also the more elaborate list of DER benefits in Lovins et al., 2002.

[47] See Feinstein and Lessor, 1998, and Feinstein and Chapel, 2000, for an alternative approach to estimating benefits from DER capacity.

[48] Iannucci et al., 2003, Tables 4 and 5, pp. 12–16.

[49] However, integrating distributed resources with the grid results in added costs to distribution utilities that must be subtracted from the expected savings from capacity deferrals. We expect to explore these tradeoffs in Phase II.

[50] For example, in Iannuci and Eyer, 1999.

[51] See footnote 37.

for conventional resources. Many of these intangible benefits seem relevant to GridWise as well.

A final category of end-user benefits not included in these Phase I estimates consists of enhanced economic productivity made possible by GridWise—over and above the efficiency improvements estimated in Chapter 3. In estimating benefits, we and others[52] have considered *efficiency* to mean producing more output with less input of electrical power.[53] *Productivity* is a broader concept referring to producing more output using less inputs of labor, capital, and all other economic factors.

The argument for GridWise as a productivity, not just an efficiency, enabler starts with the observation that innovations are first applied to improve existing business processes and only later are used to fundamentally change those processes themselves. Thus, the largest long-term benefits of GridWise may not be the lowering of end-user expenditures for power or reductions in the costs of outages and disturbances, but the enabling of end-users to redesign their production and business processes to utilize the increased power quality, reliability, and stability. The EPRI *Electricity Sector Framework for the Future* report makes this point well with respect to labor productivity:

> [H]igher productivity rates can be sustained in the future because the highly reliable digital power infrastructure means that workers can perform existing and completely new functions quickly, accurately and efficiently. In this sense, transformed power reliability and quality become *enabling* agents—they are necessary for unleashing and streamlining the digital economy. The payoff from this economic progress is the potential for creating nearly *$2 trillion per year* in additional GDP that would be available to both the private and public sectors by 2020. (EPRI, 2003b, Vol. 1, pp. 43–44; emphasis in original)

We have not estimated such potential productivity benefits in Phase I because they depend on subjective assumptions about future changes in production and business processes that, in our view, cannot yet be given a range of reasonable probabilities or plausible bounds. Instead, we have deliberately chosen to focus on benefits that can be supported analytically and refined with additional empirical data. However, we plan to explore the potential productivity benefits from GridWise further in Phase II.

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52 Kannberg et al., 2003; EPRI, 2003b.

53 More precisely, we use *efficiency improvement* to denote the reduction of delivered electricity intensity measured as kilowatt hours per dollar of gross domestic product (kWh/$GDP).

5. Plans for Phase II

Phase II will extend the Phase I work in four principal ways. First, we will seek to reduce the uncertainties in the input data and assumptions used to estimate benefits in the demand response, PQR, and efficiency modules described in Chapter 3. Priorities here include the following:

- Analyzing recent and current demand response pilot projects (such as California's Statewide Pricing Pilot) to develop better estimates for demand elasticities and future load duration curves.
- Using the most recent analyses of the costs of power outages and disturbances to reestimate GridWise benefits from improving power quality and reliability.
- Applying the results of assessments of the August 14, 2003, blackout to estimate the benefits and costs of accelerating GridWise implementation in the T&D grid.

Reducing uncertainties in the input variables will enable us to significantly narrow the range of estimates of GridWise benefits.

We intend to convene one or more expert panels to review the input data and assumptions, as well as the resulting estimates of benefits. We believe that, to the extent that funds permit, it would also be very useful to bring together experts from PNNL, EPRI, and other groups working on benefit estimates to compare and discuss models, data, and assumptions. The primary purpose of such a workshop would be to gain a better understanding of how and why results from different groups differ and how the range of uncertainties surrounding different estimates can be reduced.[54]

Second, we will evaluate categories of benefits not explicitly assessed in Phase I, including GridWise impacts on (1) deployment of distributed energy resources, (2) emissions, (3) other environmental issues, (4) externalities and intangible benefits, and (5) productivity.

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[54] The Energy Modeling Forum at Stanford University illustrates how such collaboration can improve simulation and modeling on topics characterized by deep uncertainty. See www.stanford.edu/group/EMF.

Third, we expect to use more-sophisticated modeling approaches and techniques, such as exploratory modeling, real-option analysis, and optimal-investment approaches, to produce better benefit estimates.

Finally, and perhaps most important, we will work with OETD and other DOE and industry resources to identify and assess the projected costs of GridWise, in order to develop quantitative net-benefit estimates that can inform public and private sector decisionmaking. It is necessary to understand the costs and timing of both GridWise R&D and GridWise implementation to arrive at estimates of net present values. Since most of such costs remain highly uncertain, we will develop parametric ranges of cost-driving factors, similar to the parametric ranges of input variables used for the benefit estimates in Chapter 3. Analysis of how the benefits can be aligned with the necessary investments is also important to mobilizing support for moving GridWise from vision to reality.

Appendix A

Microeconomic Discussion of GridWise-Enabled Demand Response

The GridWise concept has implications for both the efficiency of the electric power market and the welfare distribution among producer and consumer classes. In the following diagrams, consumers are end-users of electricity in the residential, commercial, and industrial sectors. The demand curve represents the horizontally aggregated demand of all end-users and for simplicity is shown as linear. The utility represents an entity that links the wholesale and retail markets, essentially selling to consumers at retail prices and purchasing electricity at the market-clearing price in the wholesale market. It can be a traditional utility, competitive electric service provider, or aggregator. Generators are producers of electric power who sell electricity into a competitive hourly wholesale market. It is assumed that the wholesale market operates in a way that dispatches generating units in order of marginal cost and the market clears at the marginal cost of the most expensive unit dispatched. The slope of the supply curve becomes very steep as more-expensive peak units are dispatched.

The Traditional Electric Power Market

In Figures A.1 and A.2, it is assumed that all end-users of electricity face the same time-invariant retail price set by a utility. The retail price does not reflect the wholesale market-clearing price at any particular time but is, rather, a price at which a utility expects to achieve an acceptable rate of return over the long run. The demand curve represents the end-users' willingness to pay for electricity and shifts throughout the day and the year. The quantity of electricity consumed in any bidding period is determined by the intersection of the aggregate demand curve and the retail price. However, the wholesale market faces a de facto inelastic short-run demand from the retail market, since consumers have no incentive to adjust their consumption due to price changes in the wholesale market. The market-clearing wholesale price (WP) is determined by the intersection of this inelastic demand curve seen by the wholesale market with the marginal cost (MC) curve of the electric power producers. Thus, the retail and

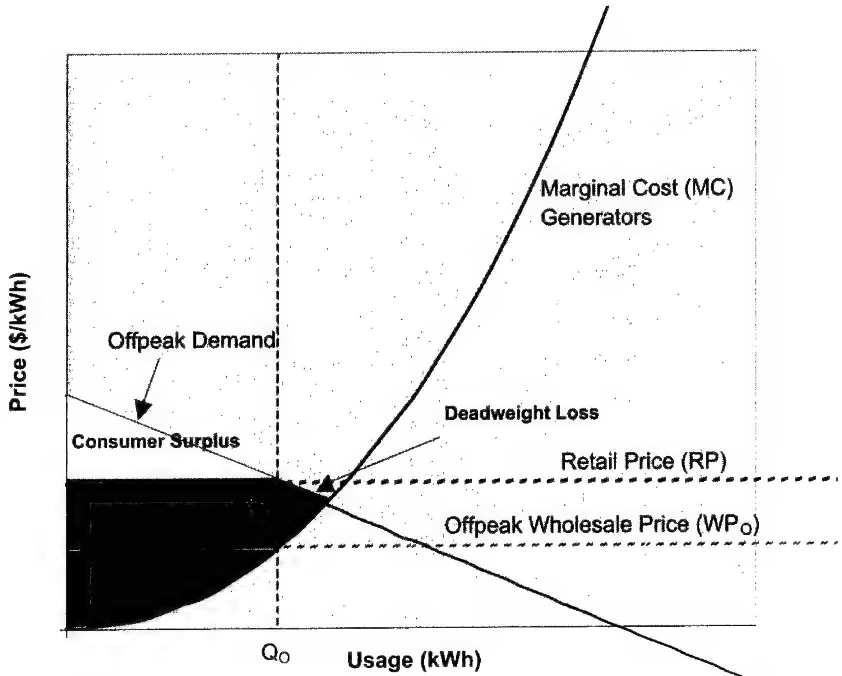

Figure A.1. Electric Power Market, Off-Peak Without GridWise

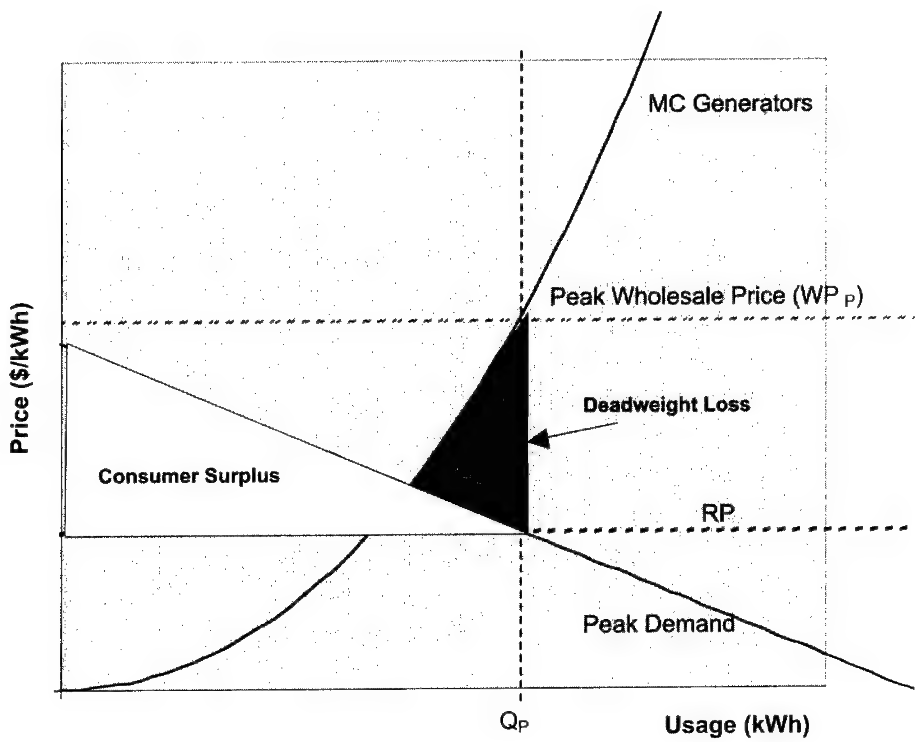

Figure A.2. Consumer Surplus During Peak Without GridWise

wholesale markets are disconnected, with the utility absorbing the price risk from the fluctuating wholesale market.

Off-Peak Without GridWise

During periods of low demand (Figure A.1), the utility enjoys a profit equal to the difference between the retail price and the wholesale price, multiplied by the quantity transacted. The consumer surplus is the integral over the consumer's willingness to pay for electricity minus the actual price paid, which is represented as the area between the retail price and the demand curve up to the equilibrium consumption point. "Inframarginal" consumers—those represented by the portion of the demand curve to the left of the equilibrium point—face a price that is below their willingness to pay, generating a surplus for the consumer class. The disconnect between the retail and wholesale markets results in a deadweight loss in this scenario, represented by the gray area in Figure A.1. End-users consume less than the socially efficient point during off-peak hours.

Peak Without GridWise

During peak hours, utilities operate at a loss in order to sustain retail prices that are below the wholesale market-clearing price. End-users consume more electricity than the socially efficient amount during peak hours (Figure A.2), and generators produce more. Both generators and consumers are essentially subsidized by the utility during peak hours.

The Electric Power Market with GridWise

Figures A.3 through A.6 illustrate the consequences of introducing the GridWise concept into the electric power market. One of the fundamental aspects of this market is that consumers face a retail price that is more highly correlated with the wholesale price—in these illustrations, they are shown to be equivalent, for simplicity.[55] It is assumed that all consumers face the wholesale hourly spot price.[56] The short-run demand curve is elastic, since consumers face fluctuating spot prices and are able to quickly adjust their consumption based on hourly price signals. The equilibrium price and quantity are determined by the

[55] Also, for simplicity, the peak/off-peak substitution effect on the demand curve is not shown in the diagrams. With GridWise, it is assumed that some portion of the peak demand would be shifted to off-peak hours.

[56] In reality, a portfolio of tariff options that would represent different levels of price risk assumed by the electricity service provider and the consumer would likely be offered in the future.

intersection of the aggregate demand curve and the marginal cost curve. Consumers now have the incentive to reduce consumption during wholesale price spikes. A portion of this reduced consumption is deferred[57] to cheaper off-peak periods, while the rest is conserved.

Off-Peak with GridWise

With GridWise, end-users consume more off-peak electricity, and deadweight loss is also eliminated, as illustrated in Figure A.3. The market-clearing wholesale price increases but is still below the original retail price. Consumer and generator surpluses are both increased at the expense of the utility, as shown in Figure A.4. Part of this surplus represents a transfer from the utility to consumers and generators. The other part represents a pure social-efficiency gain as the deadweight loss is eliminated.

The utility is not represented in Figure A.3, since the retail and wholesale prices are assumed to be equivalent. In reality, the entities along the value chain from

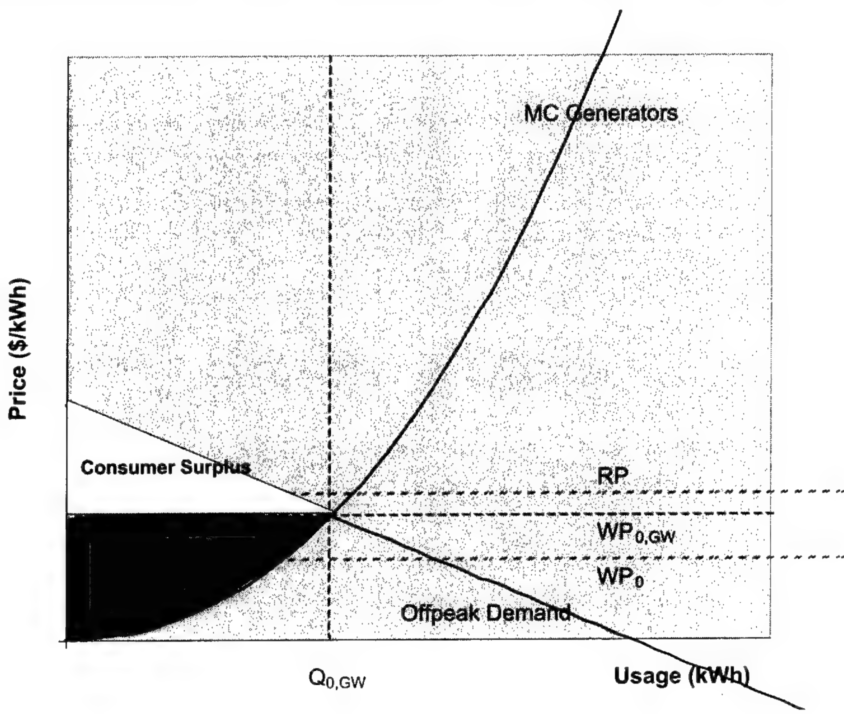

Figure A.3. Electric Power Market, Off-Peak with GridWise

[57] Represented by the elasticity of substitution between peak and off-peak hours.

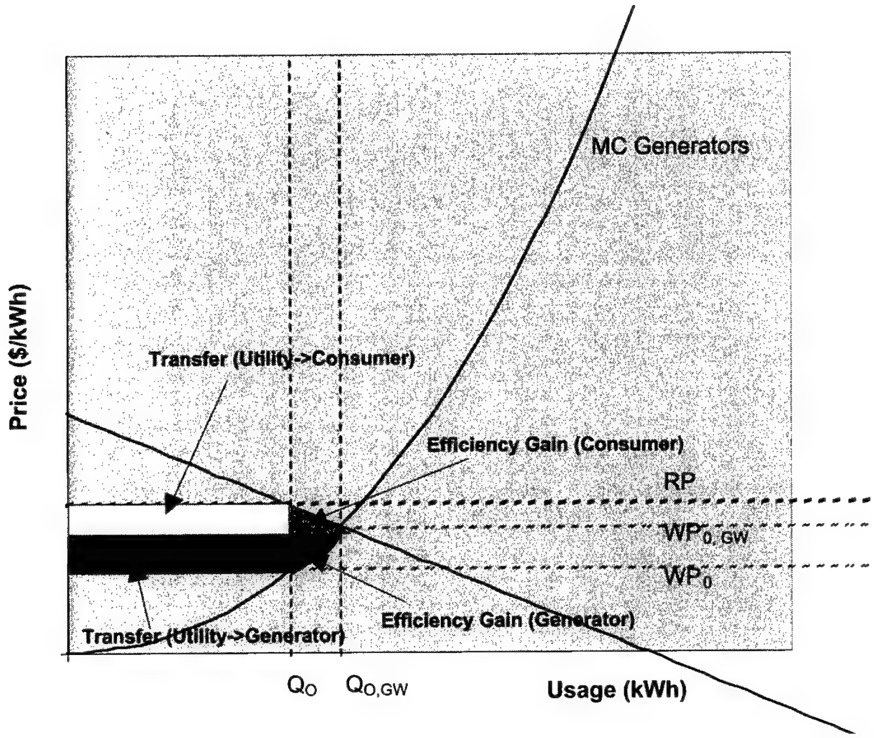

Figure A.4. Off-Peak Welfare Changes with GridWise

generators to consumers would require a rate of return on transmission, distribution, and other services, resulting in a retail markup above the wholesale market-clearing price. For simplicity, this has been omitted from these illustrations.

Peak with GridWise

GridWise would reduce consumption (and production) of electricity during peak periods, as shown in Figure A.5. Consumers would face higher prices, since they would be no longer be facing fixed retail prices, and generators would face lower selling prices, since the market-clearing price would be substantially lower. The utility, however, no longer operates at a loss during peak hours, since it receives a welfare transfer from generators and consumers, including an efficiency gain, as illustrated in Figure A.6.

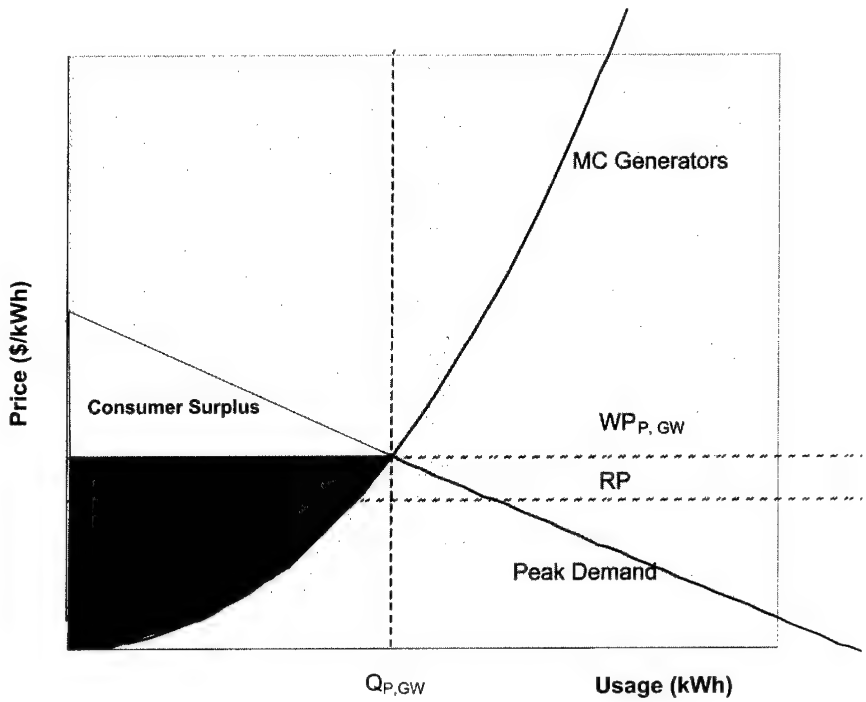

Figure A.5. Electric Power Market, Peak with GridWise

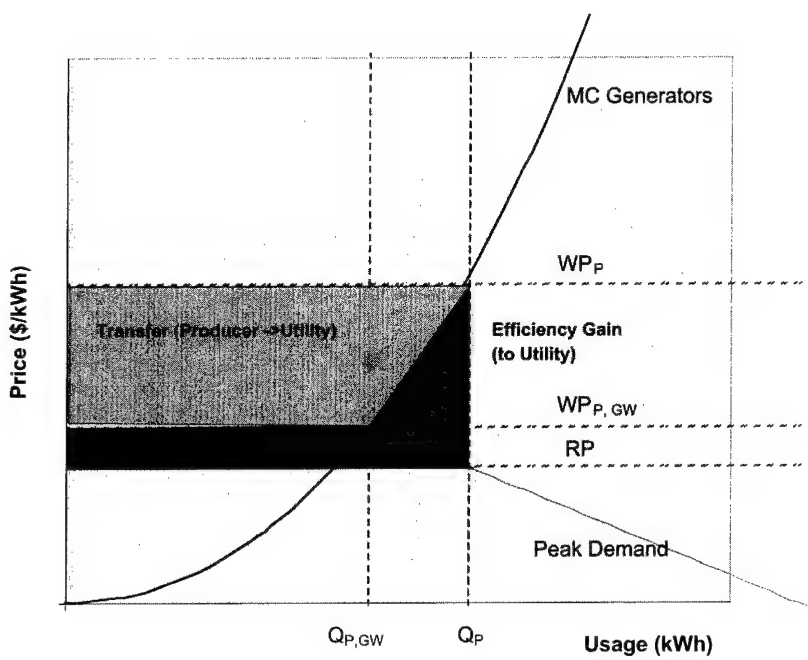

Figure A.6. Welfare Transfers at Peak with GridWise

Appendix B

Baseline Projections, 2001–2005, Without GridWise

Baseline Projections, 2001–2005, Without GridWise

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Generation - Gigawatts of Net Summer Capacity (GW)													
(data from AEO2003, Table 9)													
U.S. Electric Power Sector - Total	823.1	885.4	910.5	917.4	911.1	893.2	892.4	891.8	905.4	924.7	942.1	958.5	971.8
Selected generator categories:													
Coal steam	305.3	305.6	305.4	304.4	303.1	302.0	302.2	301.8	303.2	306.4	309.4	310.1	312.8
Combined cycle	43.6	74.8	94.0	98.8	103.6	106.0	113.4	118.8	131.9	145.0	158.5	170.2	181.2
Combustion turbine/diesel	98.1	121.0	124.5	126.6	126.8	125.3	123.4	124.0	124.6	128.2	128.6	132.3	132.5
Distributed generation	0.0	0.0	0.0	0.1	0.3	0.4	0.6	0.9	1.3	1.7	2.3	2.7	3.2
Additions to Capacity (GW) (data from AEO2003, Table 9)													
Coal steam						1.0	1.2		1.5	3.1	3.0	0.8	2.7
Combined cycle		36.9	21.1	5.6	4.5	2.4	7.9	4.3	13.1	13.2	13.5	11.6	11.0
Combustion turbine/diesel		23.7	4.4	2.1	2.1	0.0	0.6	2.1	1.2	3.9	0.9	4.1	0.2
Noncoincident Peak Load (GW)	674.8	687.9	705.3	722.9	738.5	753.3	758.5	758.0	769.6	786.0	800.8	814.7	826.0
(2001-2006 data from EIA 2001, Table 3.3; extrapolated 2007-2025 to give 15% capacity margin based on net summer capacity)													
Capacity Margin	18.0%	22.3%	22.5%	21.2%	18.9%	15.7%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fuel Cost (2001$/MMBTU) (data from AEO2003, Table 3)													
Fuel cost - coal	1.25	1.22	1.22	1.22	1.22	1.21	1.2	1.19	1.18	1.17	1.17	1.16	1.16
Fuel cost - gas	4.78	3.07	3.42	3.29	3.27	3.24	3.32	3.48	3.62	3.79	3.88	3.98	4.04

Characteristics of New Generators (data from AEO2003 Assumptions, Table 40)

Technology	Scrubbed coal	Coal-gas. combined cycle	Adv. gas combined cycle	Adv. gas turbine/ diesel
Size (MW)	600	550	400	230
Lead time (years)	4	4	3	2
Capital cost-2002 (2001$/kW)	1154	1367	608	460
Capital recovery factor	0.15	0.15	0.15	0.15
Capacity factor (from EPA_01 F5)	0.734	0.734	0.5	0.2
Capital cost/kWh (2001c/kWh)	2.692	3.189	2.082	3.938
Fixed O&M costs (2001$/kW)	24.52	33.72	10.22	8.17
Fixed O&M costs (2001 c/kWh)	0.381	0.524	0.233	0.466
Variable O&M costs (2001 c/kWh)	0.031	0.020	0.020	0.031
Heat rate (Btu/kWh)	8600	7200	6350	8550
Fuel cost in 2001 (2001 c/kWh)	1.075	0.900	3.035	4.087
Fuel cost in 2025 (2001 c/kWh)	0.946	0.792	2.921	3.933
Levelized cost in 2001 (c/kWh)	4.179	4.634	5.371	8.522

Baseline Projections, 2001–2005, Without GridWise

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Generation - Gigawatts of Net Summer Capacity (GW)												
(data from AEO2003, Table 9)												
U.S. Electric Power Sector - Total	990.2	1006.4	1018.2	1034.3	1046.9	1064.1	1076.5	1096.9	1113.1	1136.5	1149.6	1174.1
Selected generator categories:												
Coal steam	315.7	323.0	326.4	331.9	335.5	340.4	343.2	345.4	350.7	356.5	361.4	370.6
Combined cycle	192.6	197.8	202.6	209.9	215.5	223.5	228.3	238.9	244.4	255.6	260.7	270.4
Combustion turbine/diesel	136.8	139.7	142.1	144.3	146.5	149.2	152.7	159.0	163.4	168.0	169.6	173.9
Distributed generation	4.0	4.9	5.9	7.0	8.1	9.1	10.1	11.2	12.3	13.5	14.6	15.8
Additions to Capacity (GW) (data from AEO2003, Table 9)												
Coal steam	3.4	7.2	3.5	5.4	5.0	4.9	2.8	3.0	5.3	5.8	4.9	9.5
Combined cycle	11.4	5.2	4.8	7.3	5.6	8.1	4.7	10.6	5.5	11.2	5.2	9.7
Combustion turbine/diesel	4.2	3.1	2.7	2.2	2.8	4.1	3.7	6.3	4.4	4.8	2.2	4.2
Noncoincident peak load (GW)	841.7	855.4	865.5	879.2	889.9	904.5	915.0	932.4	946.1	966.0	977.2	998.0
(2001-2006 data from EIA, 2001, Table 3.3; extrapolated 2007-2025 to give 15% capacity margin based on net summer capacity)												
Capacity Margin	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fuel Cost (2001$/MMBTU) (data from AEO2003, Table 3)												
Fuel cost - coal	1.15	1.15	1.14	1.14	1.13	1.13	1.12	1.11	1.11	1.11	1.11	1.1
Fuel cost - gas	4.11	4.14	4.18	4.17	4.16	4.18	4.3	4.3	4.38	4.45	4.54	4.6

Baseline Projections, 2001–2005, Without GridWise

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Electricity Consumption (billion kWh) (AEO2003, Table 8)													
Residential	1201	1232	1279	1307	1328	1352	1376	1405	1423	1445	1464	1487	1501
Commercial	1197	1230	1248	1283	1315	1346	1377	1409	1439	1471	1505	1538	1572
Industrial	994	930	977	1003	1017	1040	1070	1101	1126	1157	1186	1212	1233
Transportation	22	22	23	23	24	25	25	26	27	27	28	29	30
Total	3414	3414	3527	3616	3684	3763	3848	3941	4015	4100	4183	4266	4336
End-Use Average Prices (2001 cents/kWh)													
Residential	8.6	8.2	7.9	7.8	7.8	7.7	7.6	7.6	7.6	7.6	7.7	7.7	7.7
Commercial	7.9	7.5	7.1	7	6.9	6.7	6.6	6.6	6.7	6.7	6.8	6.8	6.8
Industrial	4.8	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.4	4.3	4.3	4.3	4.3
Transportation	7.5	7.1	6.9	6.8	6.7	6.6	6.5	6.5	6.5	6.5	6.5	6.4	6.4
Weighted Average	7.3	6.9	6.6	6.6	6.5	6.4	6.3	6.3	6.4	6.4	6.4	6.4	6.4
Electricity Expenditure (billion 2001$)													
Residential	103	101	101	102	104	104	105	107	108	110	113	114	116
Commercial	95	92	89	90	91	90	91	93	96	99	102	105	107
Industrial	48	41	43	44	44	45	46	47	50	50	51	52	53
Transportation	2	2	2	2	2	2	2	2	2	2	2	2	2
Total	247	236	234	237	240	241	243	249	256	260	268	273	277
Average Prices by Service Category (2001 cents/kWh)													
Generation	4.7	4.4	4.2	4	3.9	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9
Transmission	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Distribution	2	2	2	2	2	2	2	2	2	2	2	2	1.9
Total	7.2	6.9	6.7	6.5	6.5	6.4	6.4	6.4	6.4	6.4	6.5	6.5	6.4

Baseline Projections, 2001–2005, Without GridWise

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Electricity Consumption (billion kWh) (AEO2003, Table 8)												
Residential	1519	1539	1562	1576	1596	1616	1640	1655	1674	1696	1722	1742
Commercial	1607	1640	1673	1707	1743	1780	1816	1854	1890	1928	1965	2003
Industrial	1254	1271	1285	1302	1320	1341	1358	1376	1398	1420	1444	1466
Transportation	30	31	32	33	34	35	36	37	38	39	41	42
Total	4410	4481	4552	4618	4693	4772	4850	4922	5000	5083	5172	5253
End-Use Average Prices (2001 cents/kWh)												
Residential	7.7	7.7	7.8	7.7	7.8	7.8	7.8	7.8	7.9	7.9	7.9	7.9
Commercial	6.9	6.9	7	7	7.1	7.1	7.2	7.1	7.2	7.2	7.3	7.3
Industrial	4.4	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.6
Transportation	6.4	6.4	6.4	6.3	6.3	6.3	6.3	6.2	6.2	6.1	6.1	6.1
Weighted Average	6.4	6.5	6.5	6.5	6.6	6.6	6.6	6.6	6.7	6.7	6.8	6.7
Electricity Expenditure (billion 2001$)												
Residential	117	119	122	121	124	126	128	129	132	134	136	138
Commercial	111	113	117	119	124	126	131	132	136	139	143	146
Industrial	55	56	57	57	58	59	61	62	64	65	66	67
Transportation	2	2	2	2	2	2	2	2	2	2	3	3
Total	285	290	298	300	308	314	322	325	335	340	348	354
Average Prices by Service Category (2001 cents/kWh)												
Generation	3.9	3.9	4	4	4	4	4.1	4.1	4.2	4.2	4.2	4.2
Transmission	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Distribution	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Total	6.4	6.4	6.5	6.5	6.5	6.5	6.6	6.6	6.7	6.7	6.7	6.7

Appendix C

Results and Input Variables, by Scenario

Results and Input Variables, by Scenario

	Scenario				
	Nominal scenario	Highly competitive, responsive markets	Less competitive and responsive markets	High impact on power reliability	Low impact on power reliability
Peak-load reduction	9.5%	15%	3.5%	9.5%	9.5%
20-yr present value of benefits ($ billions)					
Suppliers: deferred and reduced costs from demand response	34.1	38.1	11.7	34.1	34.1
End-users: lower expenditures from demand response	22.8	57.2	3.9	22.8	22.8
End-users: reduced cost of outages	15.2	18.2	12.1	49.2	4.6
End-users: lower expenditures from increased efficiency	8.9	18.2	3.9	8.9	8.9
Total Benefits	81	132	32	115	70
Input variables: no entry means same value as nominal					
real discount rate	10%				
2025 GridWise market penetration: residential	40%	67%	20%		
2025 GW mkt penetration: commercial + industrial	70%	90%	50%		
price elasticity of demand: residential	-0.15	-0.2	-0.1		
price elasticity of demand: commercial + industrial	-0.2	-0.25	-0.1		
price elasticity of supply	1				
wholesale peak price without GridWise	$0.09				
peak % of total kWh	10%				
% peak reduction shifted to off-peak	50%				
2025 generating reserve margin	12%	9%	15%		
end user % of system benefits	40%	60%	25%		
2025 EMS market penetration: residential	30%	50%	15%		
2025 EMS mkt penetration: commercial + industrial	50%	80%	30%		
2003 outage cost/yr without GridWise ($ billions)	50			100	
2025 GridWise implementation: transmission	50%	60%	40%	60%	25%
2025 GridWise implementation: distribution	25%	30%	20%	30%	15%
2025 % outages reduced: transmission	33%			50%	20%
2025 % outages reduced: distribution	20%			33%	10%

Appendix D

Estimates of Benefits for Nominal Scenario

Estimates of Benefits for Nominal Scenario

	Total												
Year		**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Summary of Benefits													
(all in billions of 2001$)													
Deferred System Capital Costs													
Generation: peak-load reduction	56.67				1.46	5.08	2.40	2.69	3.10	3.08	2.89	3.03	2.08
Present value	**24.32**				**1.33**	**4.20**	**1.80**	**1.84**	**1.93**	**1.74**	**1.48**	**1.41**	**0.88**
Generation: lower reserve margin	22.10				0.94	0.94	0.92	0.97	1.01	1.02	1.03	1.03	1.10
Present value	**8.90**				**0.86**	**0.78**	**0.69**	**0.66**	**0.62**	**0.58**	**0.53**	**0.48**	**0.47**
Transmission	20.51				0.56	1.44	0.85	0.90	1.10	1.00	1.07	0.96	0.89
Present value	**8.48**				**0.51**	**1.19**	**0.64**	**0.62**	**0.68**	**0.56**	**0.55**	**0.45**	**0.38**
Distribution	27.34				1.28	1.34	1.29	1.20	1.54	1.35	1.47	1.28	1.13
Present value	**11.44**				**1.16**	**1.11**	**0.97**	**0.82**	**0.96**	**0.76**	**0.75**	**0.60**	**0.48**
Deferred System O&M Costs	12.34				0.09	0.15	0.18	0.23	0.30	0.35	0.41	0.46	0.50
Present value	**3.77**				**0.08**	**0.12**	**0.14**	**0.16**	**0.19**	**0.20**	**0.21**	**0.21**	**0.21**
Total System Savings	138.96				4.34	8.94	5.65	5.99	7.05	6.80	6.87	6.76	5.71
Present value	**56.91**				**3.94**	**7.39**	**4.24**	**4.09**	**4.38**	**3.84**	**3.53**	**3.16**	**2.42**
Supplier Cost Savings	83.38				2.60	5.36	3.39	3.60	4.23	4.08	4.12	4.06	3.42
Present value	**34.15**				**2.37**	**4.43**	**2.55**	**2.46**	**2.63**	**2.30**	**2.12**	**1.89**	**1.45**
End-User Expenditure Savings	55.60				1.74	3.58	2.26	2.40	2.82	2.72	2.75	2.71	2.28
Present value	**22.77**				**1.58**	**2.96**	**1.70**	**1.64**	**1.75**	**1.53**	**1.41**	**1.26**	**0.97**
End-User Benefits - PQR	52.19				0.19	0.39	0.60	0.82	1.05	1.29	1.53	1.79	2.05
Present value	**15.19**				**0.17**	**0.32**	**0.45**	**0.56**	**0.65**	**0.73**	**0.79**	**0.83**	**0.87**
End-User Benefits - Efficiency	30.88				0.11	0.22	0.34	0.46	0.59	0.73	0.87	1.02	1.18
Present value	**8.87**				**0.10**	**0.18**	**0.25**	**0.32**	**0.36**	**0.41**	**0.45**	**0.47**	**0.50**
Total Benefits	222.03				**4.64**	**9.55**	**6.58**	**7.27**	**8.69**	**8.82**	**9.28**	**9.57**	**8.94**
Present value	80.97				4.22	7.89	4.95	4.97	5.39	4.98	4.76	4.46	3.79

Estimates of Benefits for Nominal Scenario

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2006-2025**
Summary of Benefits												
(all in billions of 2001$)												
Deferred System Capital Costs												
Generation-peak load reduction	3.08	2.47	3.43	2.54	3.14	1.43	3.57	1.34	3.46	2.77	3.63	56.67
Present value	**1.19**	**0.86**	**1.09**	**0.74**	**0.83**	**0.34**	**0.78**	**0.27**	**0.62**	**0.45**	**0.54**	**24.32**
Generation-lower reserve margin	1.09	1.07	1.12	1.10	1.16	1.15	1.23	1.25	1.34	1.21	1.42	22.10
Present value	**0.42**	**0.37**	**0.36**	**0.32**	**0.31**	**0.28**	**0.27**	**0.25**	**0.24**	**0.20**	**0.21**	**8.90**
Transmission	1.09	0.92	1.14	0.95	1.15	0.74	1.35	0.76	1.30	1.01	1.33	20.51
Present value	**0.42**	**0.32**	**0.36**	**0.28**	**0.30**	**0.18**	**0.29**	**0.15**	**0.23**	**0.17**	**0.20**	**8.48**
Distribution	1.48	1.20	1.58	1.24	1.57	0.83	1.89	0.84	1.75	1.30	1.78	27.34
Present value	**0.57**	**0.42**	**0.50**	**0.36**	**0.41**	**0.20**	**0.41**	**0.17**	**0.31**	**0.21**	**0.27**	**11.44**
Deferred System O&M Costs	0.58	0.62	0.70	0.73	0.81	0.84	0.96	0.96	1.08	1.14	1.25	12.34
Present value	**0.22**	**0.22**	**0.22**	**0.21**	**0.21**	**0.20**	**0.21**	**0.19**	**0.19**	**0.19**	**0.19**	**3.77**
Total System Savings	7.31	6.28	7.96	6.57	7.84	4.98	9.00	5.15	8.93	7.42	9.41	138.96
Present value	**2.82**	**2.20**	**2.54**	**1.90**	**2.07**	**1.19**	**1.96**	**1.02**	**1.61**	**1.21**	**1.40**	**56.91**
Supplier Cost Savings	4.39	3.77	4.78	3.94	4.71	2.99	5.40	3.09	5.36	4.45	5.64	83.38
Present value	**1.69**	**1.32**	**1.52**	**1.14**	**1.24**	**0.72**	**1.18**	**0.61**	**0.96**	**0.73**	**0.84**	**34.15**
End-User Expenditure Savings	2.93	2.51	3.18	2.63	3.14	1.99	3.60	2.06	3.57	2.97	3.76	55.60
Present value	**1.13**	**0.88**	**1.01**	**0.76**	**0.83**	**0.48**	**0.78**	**0.41**	**0.64**	**0.49**	**0.56**	**22.77**
End-User Benefits - PQR	2.32	2.60	2.88	3.18	3.49	3.81	4.14	4.48	4.83	5.19	5.56	52.19
Present value	**0.90**	**0.91**	**0.92**	**0.92**	**0.92**	**0.91**	**0.90**	**0.89**	**0.87**	**0.85**	**0.83**	**15.19**
End-User Benefits - Efficiency	1.34	1.52	1.68	1.88	2.06	2.29	2.45	2.70	2.90	3.16	3.38	30.88
Present value	**0.52**	**0.53**	**0.53**	**0.55**	**0.54**	**0.55**	**0.53**	**0.54**	**0.52**	**0.52**	**0.50**	**8.87**
Total Benefits	**10.97**	**10.40**	**12.52**	**11.64**	**13.40**	**11.08**	**15.58**	**12.33**	**16.66**	**15.77**	**18.34**	**222.03**
Present value	**4.23**	**3.65**	**3.99**	**3.37**	**3.53**	**2.65**	**3.39**	**2.44**	**3.00**	**2.58**	**2.73**	**80.97**

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